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JOURNAL

VOLUME 12, NUMBER 4 • APRIL, 1956

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Plastic Plane Target

Agile, high-speed performance providing realistic targets for the Armed Forces' ground-to-air and air-to-air weapons has been designed into this new plastic target drone developed by the Radioplane Company of Van Nuys, Calif., a subsidiary of Northrop Aircraft, Inc.

PUBLISHED BY THE SOCIETY OF PLASTICS ENGINEERS, INC.

If your manufacturing operations include potting, sealing, impregnating, laminating, bonding or tooling . . .

Easy to use

EPON® RESIN

can give improved mechanical and electrical properties . . . plus faster processing

Because of their excellent mechanical and dielectric properties, Epon resins are important materials in electrical and electronic manufacture. Epon resins combine high strength with low shrinkage on curing and extreme dimensional stability.

For potting, sealing and impregnating, Epon resins permit safe enclosure of delicate components, maintain high insulation resistance under extremes of temperature and humidity, and are resistant to chemicals.

Epon resins laid up with inert fibrous fillers produce laminates that have excellent dielectric properties and can be sheared, punched, drilled and bath soldered.

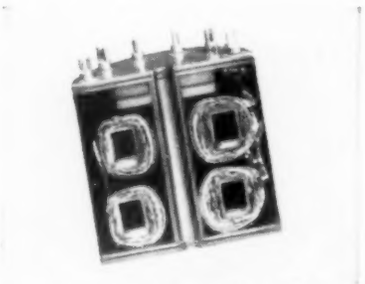
Solvent-free Epon resin adhesives, curing with contact pressure alone at room temperature, form powerful bonds between glass, metal, wood or plastic.

Because of dimensional stability and impact resistance, Epon resins play the key part in making plastic tools such as forming dies, jigs, patterns, templates and fixtures.

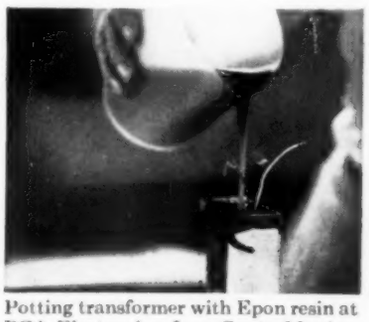
Write for "Epon Resins For Structural Uses." Your letterhead request will bring you a sample for evaluation.

(Epon resins are the epoxy polymers manufactured exclusively by Shell Chemical Corporation.)

Miniature electronic components potted in Epon resin by Freed Transformer Company, Brooklyn, New York.



Section of magnetic amplifier coils embedded in Epon resin by Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.



Potting transformer with Epon resin at PCA Electronics, Inc., Santa Monica, California.

SHELL CHEMICAL CORPORATION

CHEMICAL SALES DIVISION, 380 Madison Avenue, New York 17, New York

Atlanta • Boston • Chicago • Cleveland • Detroit • Houston • Los Angeles • Newark • New York • San Francisco • St. Louis

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Du Pont "Watchung" Pigments for Plastics

offer compounders excellent heat stability and resistance to crocking and migration. These Du Pont pigments possess good dispersibility and lightfastness. "Watchung" Reds are available in a wide shade range, and rigid quality control during manufacture is assured by thorough testing.

If you're making or compounding plastics, these Du Pont pigments may help you produce new and improved products. For technical help with any plastics pigmenting problem, consult Du Pont. Technical experts will gladly work with you in finding a solution. For full information about Du Pont pigments and technical service, call your Du Pont representative, or write: E. I. du Pont de Nemours & Co. (Inc.), Pigments Department, Wilmington 98, Delaware. In Canada—Du Pont Company of Canada Limited, P. O. Box 660, Montreal, Canada.

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QUALITY PIGMENTS FOR PLASTICS

"WATCHUNG" RED RT-428-D

U.S.I. POLYETHYLENE PROCESSING TIPS

Tailormade resins, a trend for the future

The nation's leading industrial forecasters predict a polyethylene consumption of 850 million pounds for 1960 — with the billion-plus pound per year goal only a few years away. Although much of this increased production will be consumed by end-products already on the market, many new applications and new developments are expected to arise with the increased availability of polyethylene resin.

Polyethylene molders and extruders, long accustomed to working with a limited number of polyethylene types, will exercise increasing influence over the properties of the basic resin. Resin suppliers will work more and more closely with the converters, especially manufacturers of new products, to supply them with resins having the best possible properties for each new application. This is a trend already well established.

For example, here are a few of the 25-35 PETROTHENE® resins and variations that have already been tailored to specific processing situations and new end-use applications.

1. INJECTION MOLDING: Molders want high flow for maximum production, high gloss for appearance, and a choice in degree of flexibility. PETROTHENE 202 and 203 have been tailored for large shot moldings; 200 and 201 for smaller shots and multiple cavity dies.

2. FILM: PETROTHENE 110 and 210 are tailormade for blown- and flat-film extrusions. Degree of slip can be controlled to meet customer requirements. PETROTHENE 213 has been selected in specific cases for transparency, hand and high production rates.

3. PAPER COATING: Converters want good adhesion, high production rates, resistance to hot-melt oxidation, no odor. PETROTHENE 203 has been tailormade to fit these specifications. It has been accepted by the pulp and paper industry as an improvement in paper-coating raw material and is gaining in popularity for this vital and expanding application.

4. ELECTRICAL: The wire insulation manufacturer requires polyethylene that gives stress-crack resistance, low deformation under load, and good all around electrical characteristics. PETROTHENE 300 series has been tailored to these end-use requirements. Type and quantity of antioxidant and color are specified by the customer or by the electrical specification code number.

5. BLOW MOLDING: Cube-to-cube uniformity, hot-melt elasticity, clarity — all essential properties for this critical application — have been built into PETROTHENE 201. Other PETROTHENE types have been used in some cases for blow molding because of customers' unusual processing techniques.

6. EXTRUSION: PETROTHENE 560 (black) was designed to give good burst strength, high gloss and high extrusion rate for pipe manufacturers.

7. SPECIALTY APPLICATIONS: Requests come in for special properties, special forms. U.S.I. has tailored each resin type to fit customer requirements so as to help the converter reach mass production and enjoy greater economies. Thus the converter can obtain his full share of profits from this forecasted billion pound market.

SUGGESTED PETROTHENE® RESINS

Application	PETROTHENE No.
Blow Molding	201
Electrical	300 Series
Film	110, 210, 213
Injection Molding	
Large Shot	202, 203
Small Shot	200, 201
Paper Coating	203
Pipe extrusion and misc.	560 (Black)

Do you need a special resin?

If your polyethylene product requires special properties, either in the finished part or during processing, why not call on U.S.I. for assistance. Experienced Technical Service personnel will work with you on every phase of your problem. A U.S.I. PETROTHENE resin, already developed for a similar application, might be just what you need. If not, depending upon the quantity involved, a special resin, tailored to your needs by U.S.I., might provide the answer.

Tomorrow's prices will encourage new uses

Today's costs of producing quality polyethylene resins are relatively high and constant, but experts feel that as producers improve quality and increase production, lower selling prices will follow. New products, now undreamed of, will be developed within the next few years to utilize the large available volume of this versatile plastic.

U.S.I. INDUSTRIAL CHEMICALS CO.
Division of National Distillers Products Corporation
99 Park Avenue, New York 16, N. Y.
Branches in principal cities

SPE JOURNAL

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• *Entered as second-class matter at the Post Office at Athens, Ohio.*

This 500-pound sheet of rigid polyvinyl chloride, claimed to be the largest ever made, has been produced by Seiberling Rubber Co. plastics division at Newcomerstown, Ohio. A two-inch gauge sheet, it measures 48" by 96". The company also produces 1-¼", 1-½" and 1-¾" gauge sheets.

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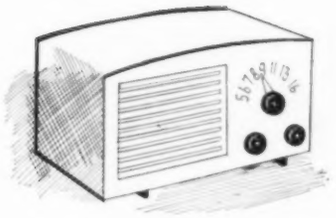
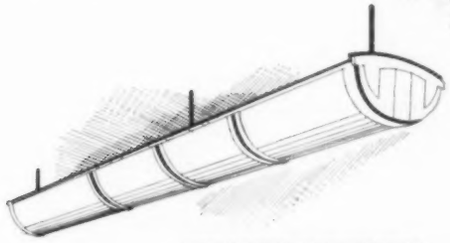


DURABILITY

STRENGTH AND SURFACE HARDNESS

ELECTRICAL PROPERTIES



TRANSLUCENCY

SURFACE BEAUTY

To give their "Old Spice" toiletries an extra sales lift, Shulton, Inc., decided to revamp its packages. The new design called for thermo-setting "reverse taper" bottle closures—a tough molding job at best.

The molder selected PLASKON Urea Molding Compound for the job. Why PLASKON Urea? Because this versatile material molded well in the varying cross sections and contours of the Old Spice closure, and its rapid rate of cure permitted higher-volume, lower-cost, top quality production.

This is another instance where PLASKON Urea has simplified a molding job. Why not find out if it can do the same for you? Your Plaskon man stands ready to furnish you with complete data and technical assistance on all your molding problems.

Glowing surface beauty and a range of over 13,000 molded-in colors make PLASKON Urea highly suitable for closures, radio and TV cabinets and hundreds of other products.

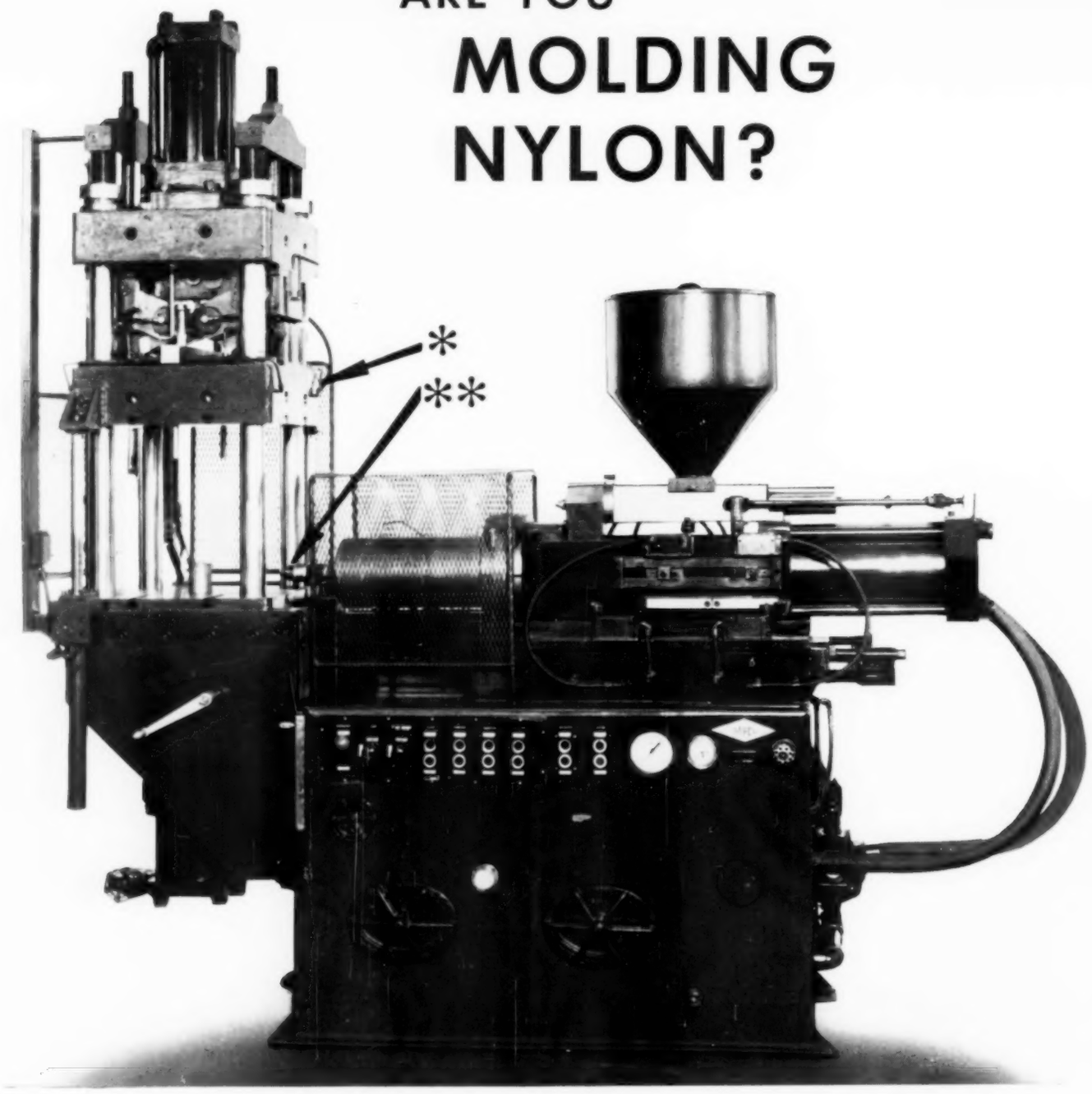
PLASKON Urea has high dielectric strength and arc resistance. That's why it's ideal for use in wall plates, sockets and electrical appliances such as shavers, clocks and lamps. The surface is very hard, scratch-resistant and easy to clean.

Barrett PLASKON

If you'd like more information on PLASKON Plastics and Resins, write or call: Barrett Division, Allied Chemical & Dye Corporation, 40 Rector St., New York 6, N. Y.—HAnover 2-7300.

leader in the field

ARE YOU MOLDING NYLON?



IMPCO VA4-175-19 — 4-6 OUNCES

SPECIFICATIONS

Injection Capacity	4-6 oz.
Injection Pressure (Plunger)	21,750 p.s.i.
Plasticizing Capacity (Polystyrene)	75 lbs. hr.
Clamp Pressure (Toggle)	175 tons
Clamp Stroke	8"
Die Thickness	Max-14" Min-8"
Machine Cycle (Dry Run)	7 Min.
Auxiliary Bottom Ram	19 Tons
Dimensions	Length-102", Height-112", Width-60"
Weight	Approx.-9000 Lbs.

**No drool problem with this easily controlled check valve type nozzle.

*Vertical type press-ideal for insert molding.

If you are a nylon molder, you must investigate this Impco machine!

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IMPROVED MACHINERY INC.
NASHUA, NEW HAMPSHIRE

Phenolic molded device makes flashlight

Safe in explosive atmospheres

Safety is achieved by use of a spring-loaded contact within the reflector assembly so designed that if the bulb of the lamp is broken, the electrical circuit will be instantly opened before the filament can ignite inflammable or explosive mixture of gas in the surrounding atmosphere.

The intricate working parts of the reflector assembly are molded of BAKELITE Brand Phenolic Plastic BMG 5000 Black. Their positive, unhampered action demonstrates the dimensional stability and strength of this material. In production, the reflector unit with its mounts and guides, exterior threads, and slots for the wire guard are formed in one operation with a 9-cavity compression mold. The retainer ring that holds the wire guard is produced in a 12-cavity high-speed plunger mold.

For further information on a wide range of phenolic plastics, write Dept. OP-171

Reflector assembly parts made of BAKELITE Phenolic Plastic by **Auburn Button Works, Inc.**, Auburn, N. Y., for "Eveready" Safety Type Flashlight, produced by National Carbon Co., A Division of Union Carbide and Carbon Corporation, N. Y. 17, N. Y.

BAKELITE
BRAND
PHENOLIC PLASTICS

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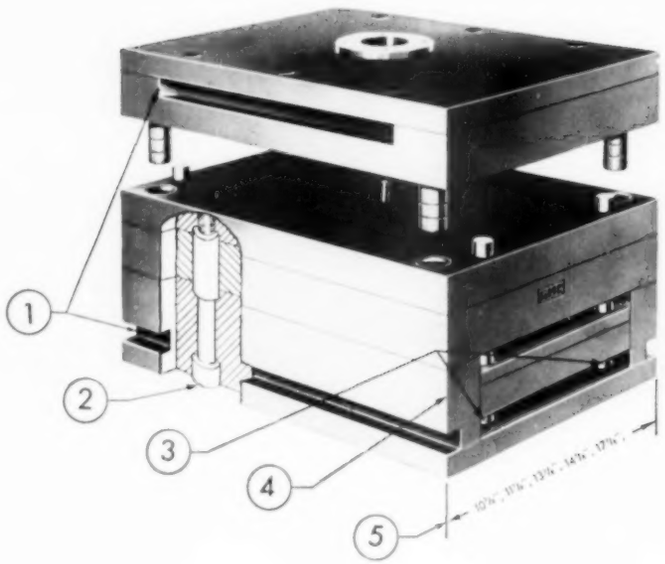
ON D-M-E STANDARD MOLD BASES!

EXPANDED FACILITIES SAVE YOU TIME . . !

Now . . . you can get FASTER DELIVERIES on the highest quality Standard Mold Bases even though the demand has reached an all time high!

This availability has been made possible by the recent expansion in D-M-E's manufacturing facilities. With D-M-E's Hillside, New Jersey plant doubled and additions at the Detroit, Michigan plant completed, production of Standard Mold Bases is now geared to meet the ever-increasing demands of the Industry.

This increased production has enabled D-M-E's FIVE BRANCH WAREHOUSES to replenish their stocks and provide IMMEDIATE DELIVERIES on a wide range of standard sizes . . . This means ADDED SAVINGS in mold construction time as well as ECONOMY in mold costs for you!



(9" wide series available with clamping ledges and solid dowels.)

4,400 COMBINATIONS SAVE YOU MONEY . . !

22 Standard Width and Length combinations . . .
From 9" x 8" to 17⅞" x 35½"

100 Cavity Plate Combinations . . .
From ⅞" thick to 5⅞" thick

2 Special Types of Steel . . .

DME No. 1 Steel —
Medium Carbon, silicon killed

DME No. 2 Steel —
SAE 6145, electric furnace grade, pre-heat treated to 225 Brinell.

For complete data and prices . . .
CONSULT YOUR NEW D-M-E CATALOG!

YOU GET TOP QUALITY PLUS THESE ADDED FEATURES!

1. **CLAMP SLOTS to Save Platen Space**
   Eliminates space-wasting "clamping ledges"
2. **MORE ROOM for Waterlines**
   Tubular Dowels eliminate obstruction
3. **STOP PINS WELDED to Ejector Bar**
   Prevents loosening and ejection interference
4. **RIGID CONSTRUCTION with Less Parts**
   One piece Ejector Housing gives added strength
5. **NEW WIDTHS Fit More Molding Machines**
   Allows more cavities to existing platen area

CONTACT YOUR NEAREST D-M-E BRANCH . . . TODAY!

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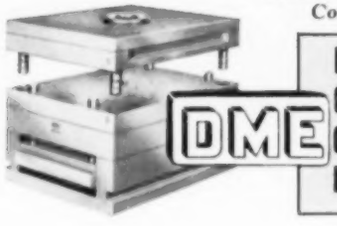
Contact Your Nearest Branch FOR FASTER DELIVERIES!

D-M-E MASTER LAYOUTS are available for each of the 22 different Standard Mold Bases sizes! See Page 164 of your D-M-E Catalog for complete ordering information.



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PRECISION CONNECTORS with KEL-F plastic parts have high RF insulation and dimensional stability. Plastic's high impact and compressive strength permit rough handling without chipping, cracking, or deforming. Zero moisture absorption and anti-adhesive surface prevent formation of conductive residue.

KEL-F® FLUOROCARBON PLASTIC

permits components to operate over a wider temperature range . . . under highly humid and corrosive atmospheres

KEL-F plastic's unique combination of properties can help your product meet more rigid performance specifications. Because of the extreme stability of the fluorocarbon plastic molecule, this dense, tough thermoplastic has superior dielectric properties, excellent resistance to corrosive chemicals, outstanding thermal and dimensional stability, and zero moisture absorption.

Molded and extruded parts operate over an extremely wide range of temperatures (−320° F. to 390° F.) . . . are unaffected by humidity or operational vibration. Metal inserts, lugs and contacts are held firmly, forming a hermetic seal.

KEL-F plastic is available from Kellogg as a molding material, or in sheets, rods, strips, tubing, film and "spaghetti" from qualified fabricators and molders throughout the country. For further information, write: The M. W. Kellogg Company, Chemical Manufacturing Division, P. O. Box 469, Jersey City 3, N. J.

KELLOGG

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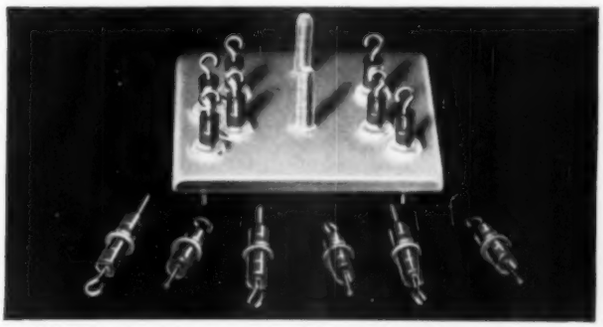
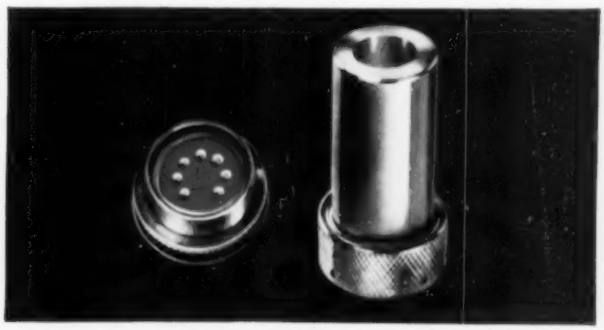
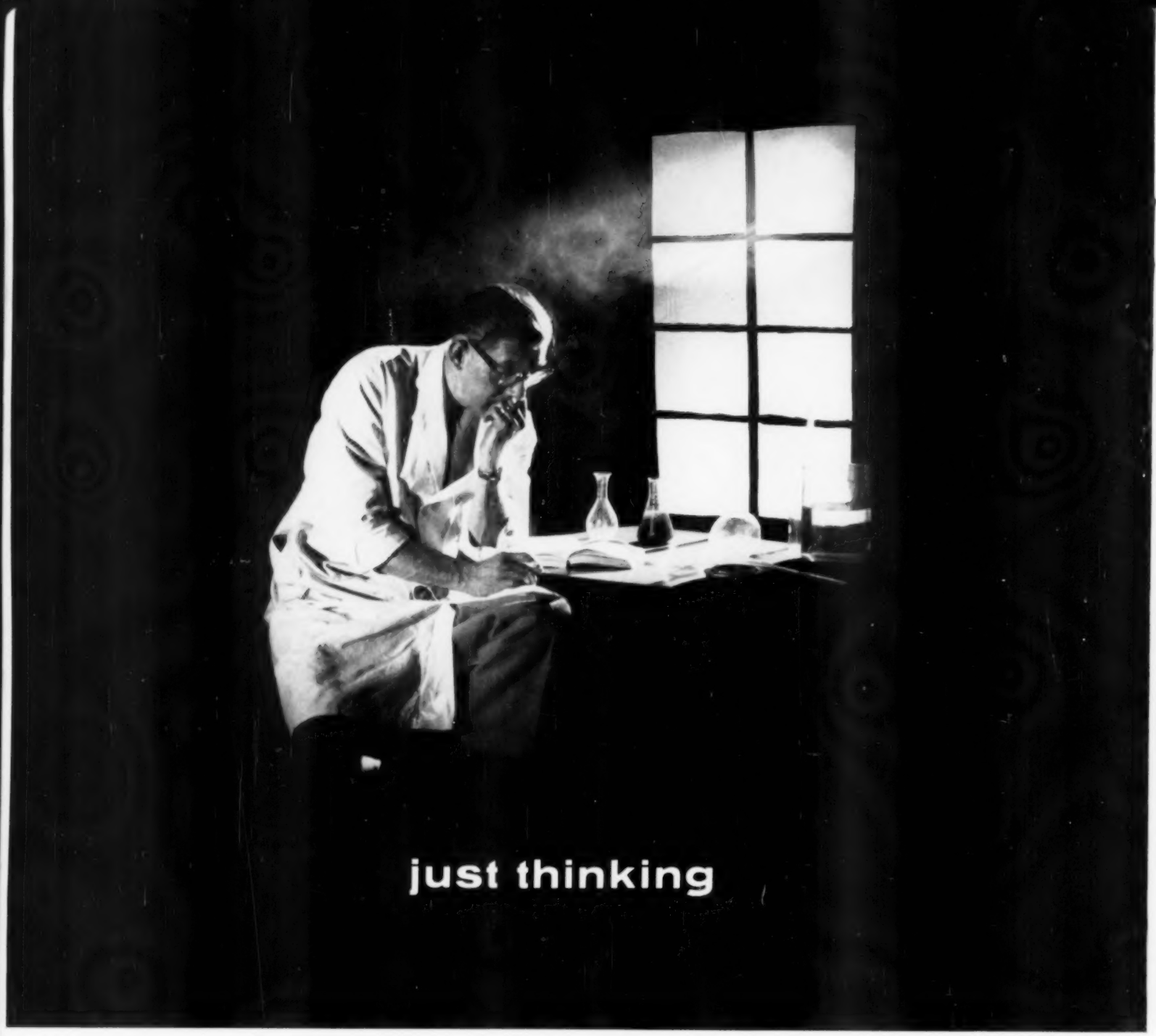
The M. W. Kellogg Company for its fluorocarbon products.



HERMETICALLY-SEALED TERMINALS with KEL-F plastic insulation handle high voltage without flash-over or tracking. Won't shrink, swell, age or lose hermetic seal at high and low operating temperatures. Can be used in contact with highly corrosive chemicals.



TUBE SOCKETS of tough KEL-F plastic. Hermetic seal defies thermal cycling, aging and humidity. Withstands high shock loads without chipping or cracking insulation. Plastic's high dielectric strength prevents shorting or arc-over at high altitudes.



Chemical progress is autoclaves, test tubes, distillation towers . . . hydrocarbons, heterocyclic compounds . . . processes, polymerizations, products.

But mostly, chemical progress is thinking . . . *men* thinking. Little men, big men, medium size men . . . in lab coats, business suits, overalls . . . all of them, always, thinking.

Thinking up new products . . . new ways to make chemicals and new ways to use them. Thinking up more comfort, more convenience, better health, for everyone.

Always, the old things have to be improved, and the new things have to be proved. It takes more thinking. The thinking never stops. And so chemical progress never stops.

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• • •

Koppers Company, Inc., Chemical Division, Pittsburgh 19, Pa., producers of styrene, Dylex styrene butadiene latices, dbpc* antioxidant, resorcinol, potassium cyanide solution, phthalic anhydride, and many other chemicals.*

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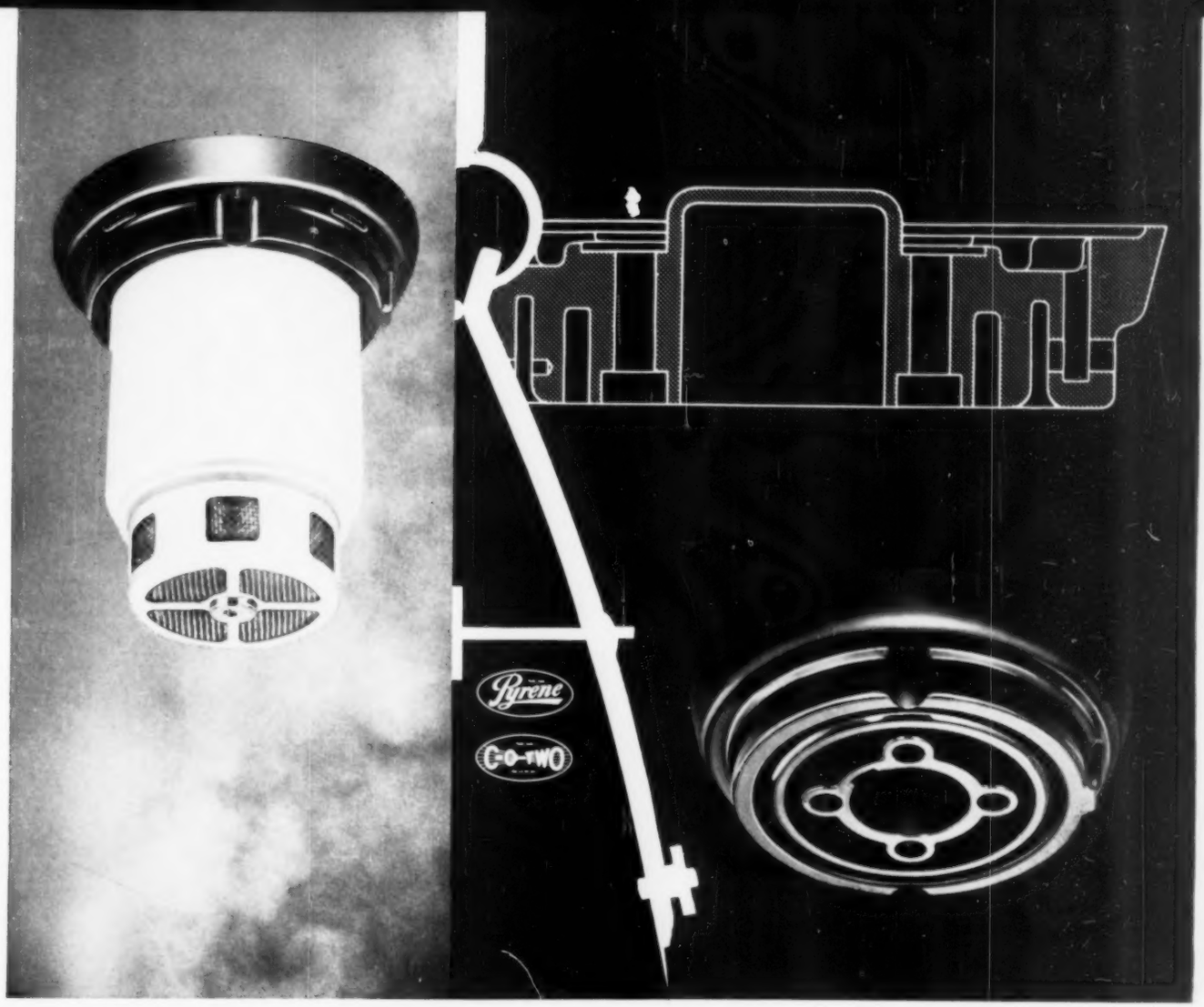

it's DURITE for the new Pyrene—C-O-Two fire guard

This remarkable fire protection device, approved by Underwriters' Laboratories, Inc. utilizes radio-active material to sense the combustion gases and smoke which precede the outbreak of flame. The compact C-O-Two Pre-Detector Heads are fastened to the ceiling in strategic locations throughout a building and must be trouble free over a long service life. Since accurate assembly is vital to perfect operation, key molded parts must have and retain a high degree of dimensional stability.

To assure this lasting dimensional stability . . . the engineers of both the Pyrene—C-O-Two Corporation and their molder, Shaw Insulator Company, chose Durite GP-102 general purpose phenolic molding compound.

A combination of many useful properties has made Durite GP-102 an industry leader among general purpose compounds. Because it assures ease in molding, rapid cure, batch-to-batch uniformity, and lustrous appearance . . . you can be sure of consistently high output and satisfied customers when parts are molded with GP-102.

Whether the parts you mold are large or small, intricate or simple . . . you'll find that Durite GP-102 can make them *better*. Why not prove this to yourself with a trial run at your own plant? Contact The Borden Company, Chemical Division, Durite Products Dept. PW-46, 5000 Summerdale Ave., Philadelphia 24, Pa.

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THE *Borden* COMPANY

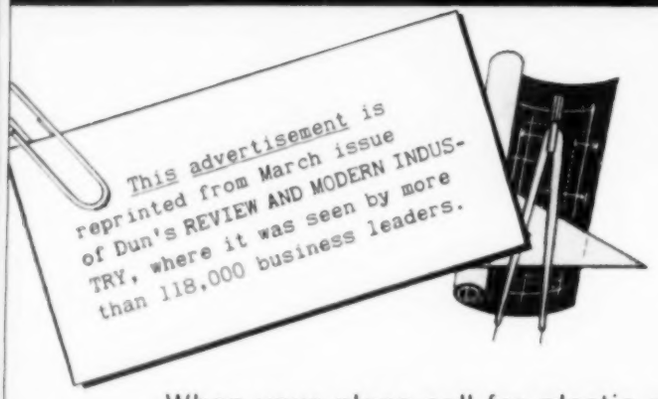
CHEMICAL DIVISION

Phenolic Molding Compounds • Abrasive and Frictional Bonding Resins • Molding and Specialty Resins • Lamp Basing Cements

This advertisement appears in
PLASTICS WORLD—March, 1956, *and* MODERN PLASTICS, *and* SPE JOURNAL—April, 1956

Craftsmen of the 20th Century

No. 13 of a series to introduce you to some of industry's outstanding plastics craftsmen

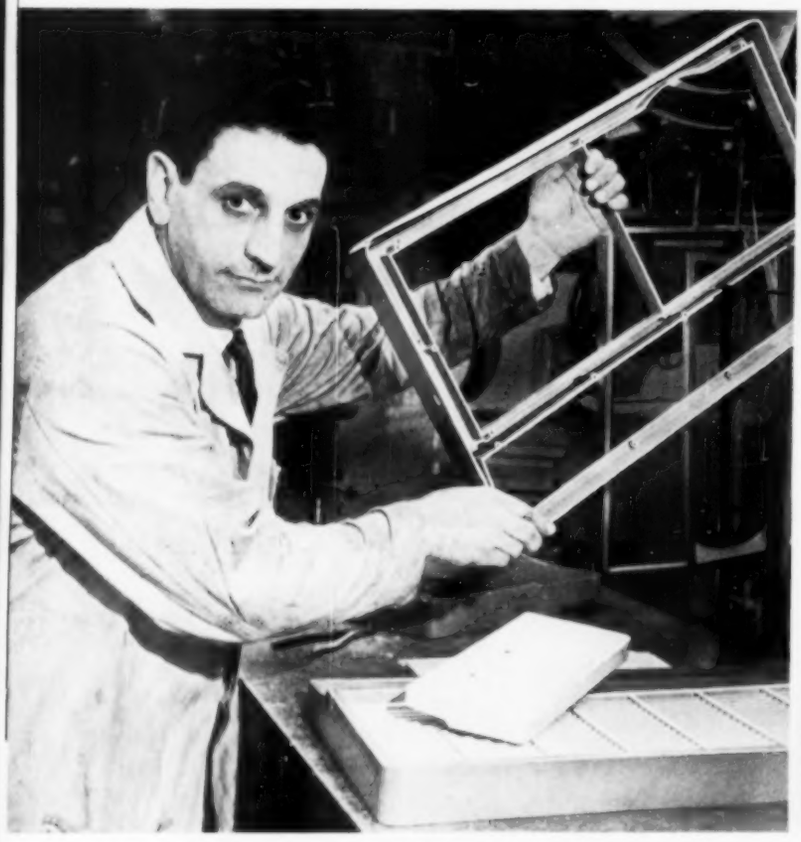

This advertisement is
reprinted from March issue
of Dun's REVIEW AND MODERN INDUS-
TRY, where it was seen by more
than 118,000 business leaders.

Artisans used to work with gold and silver, steel and glass and stone.

Their achievements were always inspired by a determination to master a material. The same driving urge dominates the men of our time who have elected to work with the newest materials of all – the fabulous family of plastics. Their skills and ingenuity are every day producing millions of low-cost articles that are serving homes and industries the country over.

Two of these 20th Century craftsmen are pictured on this page. Monsanto, a major supplier of high-quality plastic materials, salutes these men who are helping mold America's tomorrow.

When your plans call for plastic parts or products, consult an expert custom molder



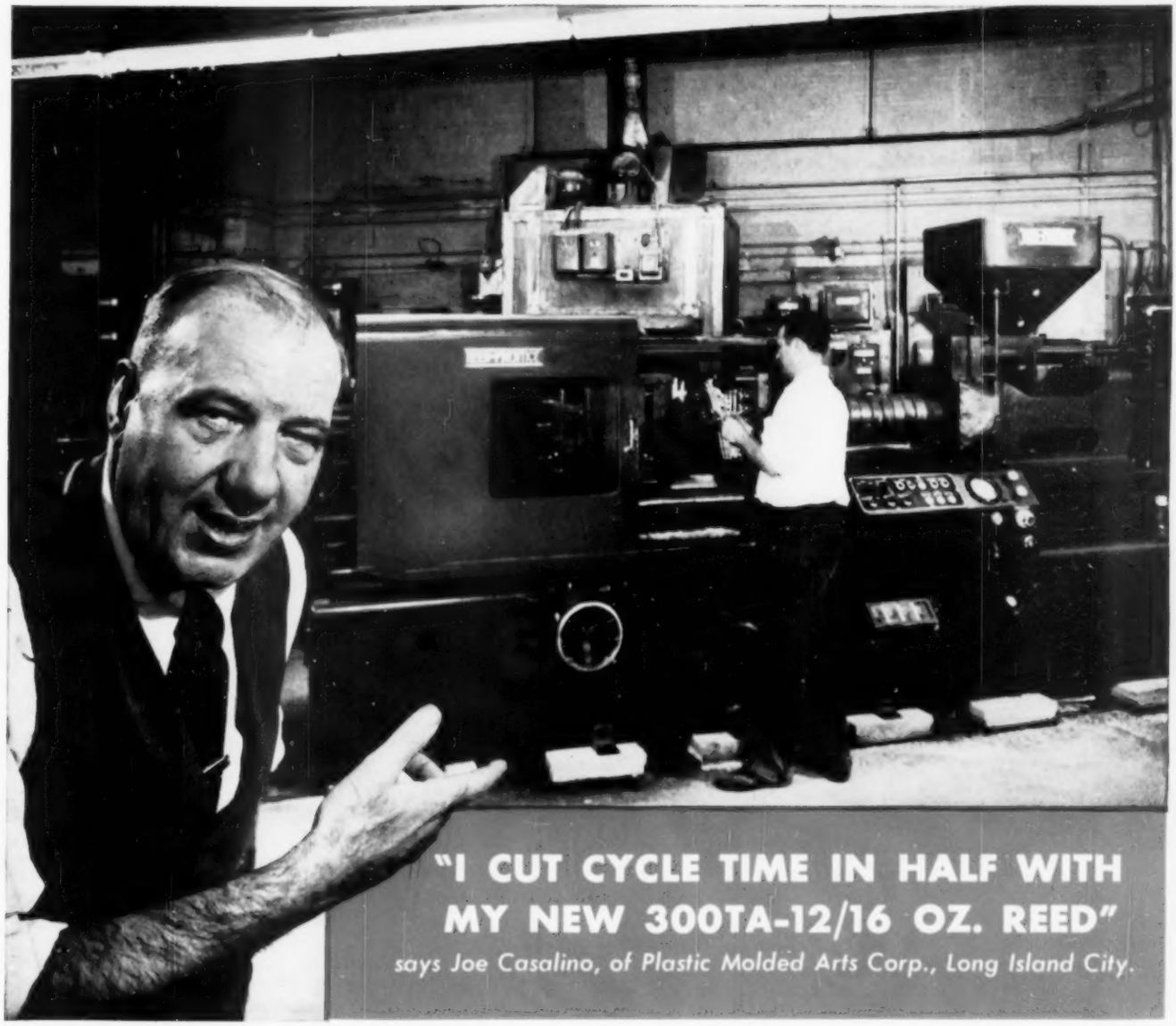
Louis E. LaCastro, Buffalo Molded Plastics, Inc., Buffalo, New York. With a record of 14 years' experience in injection molding behind him, Mr. LaCastro joined Buffalo Molded Plastics in 1953 as Superintendent of the Buffalo plant. "The latest information about our craft is not taught in engineering schools," Mr. LaCastro admits. "What we are doing today will be written into the textbooks of the future." His company specializes in molding large plastic components for refrigerators, radios, television sets, air conditioners and decorative parts for automobiles.

Stanley W. Leonowich, Thermoplastic Division of The General Industries Company, Marysville, Ohio. A chemistry set in high school fired Mr. Leonowich's early interest in plastics and he joined G.I. after working in several metal and die shops. Today, as Plant Manager, he supervises the production of approximately 600,000 molded parts a week. Mr. Leonowich specializes in the injection molding field where dies range from several hundred pounds to three or four tons. Custom components he has engineered include refrigerator parts, radio cabinets, light louvres and battery cases.

MONSANTO CHEMICAL COMPANY,
PLASTICS DIVISION, SPRINGFIELD 2, MASS.

MONSANTO

LUSTREX
Styrene Plastic



"I CUT CYCLE TIME IN HALF WITH MY NEW 300TA-12/16 OZ. REED"

says Joe Casalino, of Plastic Molded Arts Corp., Long Island City.

"We've been a solid Reed-Prentice shop since 1938," Mr. Casalino says, "and I think the 300TA design they just brought out is one of their finest injection machines yet. On my new model, I've been able to cut cycle time *in half* with the same dies. This 300TA is tops for economy and efficiency, and I've already ordered another one equipped for fully automatic operation."

You can take it from one of the leading custom molders: the new 300TA-12/16 oz. "REED" gives you more for your money. Its six big, new design features mean low-cost, efficient operation, rugged construction and easier maintenance.

Call your nearest Reed-Prentice Sales Engineer today. He'll be glad to give you complete information at no obligation.

REED-PRENTICE

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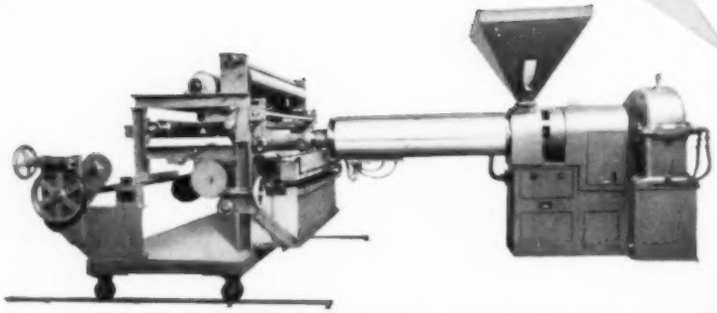

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Calculation of Roll Separating Forces in the Calendering and Milling of Plastics

A method is described for computing the force tending to separate calender and mill rolls during the processing of plastic materials. The method makes use of an equation derived by Ardichvili and an apparent viscosity value appropriate to the particular plastic and rolling conditions. This viscosity value is obtained from extrusion plastometer measurements. It is shown that computed separating forces agree with measured values in the rolling of polyethylene and plasticized vinyl materials.

F. D. Dexter and D. I. Marshall

Bakelite Division
Union Carbide and Carbon Corp.

IN THE CALENDERING and milling of plastic materials, where the material is formed into thin sheets by being pressed between two rolls, the forces tending to separate the rolls may be very large. It is desirable to be able to predict these forces for two primary reasons. First, the bearings and shafts must be able to withstand them without the risk of fatigue failure, and second, some compensation must be made for the bending of the rolls in order to produce flat sheets. In the design of calenders the practice has been to estimate the forces from experience with similar machines. Obviously it is desirable to be able to calculate the required values.

Several solutions of the pressure distribution problem in calendering have been reported, each assuming Newtonian flow behavior. Ardichvili (1) carried out the derivation based on simplifying assumptions similar to those used later by Eley (2), with essentially the same results. Both assumed that the pressure dropped to zero as the material passed through the nip. Gaskell (3) showed that the elevated pressure actually must extend past the nip even in the absence of elastic recovery, because the average velocity through the nip is greater than the velocity of the roll surfaces. This theoretical conclusion was confirmed by the roll pressure measurements of Bergen and Scott(4), who employed a pressure-sensitive element mounted at the surface of a roll.

Gaskell extended his theory to apply it to Bingham body type non-Newtonian flow, unequal roll diameters, differential roll speeds and differential temperatures. Other extensions of theory include treatment of the temperature rise from mechanical energy by Eley (5) and, in more involved form, by Finston (6).

None of the papers cited attempt to compute absolute values of roll loads for highly non-Newtonian plastics of known flow behavior. Eley (2) reported the only comparison of theory with experiment, meeting a moderate degree of success. It is the purpose of the present paper to report a method of expressing the apparent viscosity of viscoelastic materials based on simple extrusion plastometer experiments, and to show that the use of this viscosity in the roll load equations yields results which agree with load measurements. The calculation is based on the Ardichvili equation, avoiding the lengthy graphical integrations that would be required to use the more realistic Gaskell equation.

Method of Calculation

The following quantities are needed for computing the separating force in calendering or milling of plastic materials:

a. Radius of the rolls.
b. Rate of rotation of the rolls.
c. Distance of closest approach.
d. Length of roll between guide plates.
e. The mean material temperature.
f. An apparent viscosity value appropriate to the rolling conditions.
g. The thickness of the rolling bank.

The following equation, due to Ardichvili (1), is used:

$$F = 2\eta V r L (1/h_o - 1/H) \qquad (1)$$

where F is the total force tending to separate the rolls, η is the apparent viscosity of the material, L is the length of roll contacting the material, and the other symbols are as designated in Figure 5. For large bank sizes the second term in parentheses becomes very small and often can be neglected. The apparent viscosity values for substitution into Equation (1) were based on capillary flow experiments as described in a later portion of this paper. Using this method it is possible to greatly simplify the non-Newtonian flow problem by taking advantage of the fact that the velocity front in flow through circular tubes is of the same form as that in unidirectional flow between parallel plane surfaces. The effect of shear rate and the effect of period of time that the material is subjected to shear are readily taken into account when this similarity exists.

Experimental and Computed Results

Roll separating forces computed by the method described above have been compared with measured values. The measurements were made by Rocky and Carey (7) on a two-roll mill equipped with a load measuring system consisting of strain gage bridges mounted on each of two take-up screws. This arrangement provides a precise measure and continuous record of separating force. Eight in. by 16 in. rolls, with a speed of 53.5 ft./min. and a standard roll separation of 0.015 in., were used. Under these conditions, Equation (1) may be reduced to

$$F = 8.27 \times 10^4 \eta \qquad (1A)$$

where F is in lbs. and η is in lb. sec./in.^{2} Conversely, apparent viscosity may be computed from the observed F value using Equation (1A).

Typical results comparing measured with computed separating forces are listed in Table I. In the case of the vinyl compounds the results show the effect of plasticizer content; this effect on viscosity is discussed later in this paper. The polyethylene sample was a commercial product designated Bakelite polyethylene resin DYNH, flow properties of which are described later in this paper. The phenolic resin was a novolak (non-hardening) resin

with nearly Newtonian flow behavior, the viscosity of which was measured by extrusion plastometry in the shear rate range of the roll-mill experiment and found to be 1.5 x 10^4 poises. Because of the high separating force, the phenolic resin was rolled with a greater roll clearance than standard.

In a separate experiment performed by Carey (8), the bearing load on an 18 in. x 48 in. calender was measured by a similar resistance strain gage arrangement. The load during production of vinyl film was 60,000 lbs., while the corresponding computed value is 55,000 lb.

The agreement between measured and computed separating forces was sufficiently close in all of the experiments with thermoplastic materials to confirm the usefulness of the method for engineering calculations. In the case of the phenolic resin, which had a high viscosity and high sensitivity of viscosity to temperature, there was greater deviation — probably because of uncertainty in the temperature reading.

Separating forces for several calendering machines under various operating conditions have been computed and are listed in Table II.

These results give an indication of the range of forces involved in calendering and how they can be expected to vary with material type, temperature, sheet thickness, and roll speed.

Flow Properties

To calculate roll separating force by means of Equation (1) a suitable viscosity value is required. In this section it will be described how capillary tube flow measurements may be used conveniently for this purpose. Flow property results obtained on plasticized vinyl compounds and polyethylene, measured with an extrusion plastometer, are presented.

There are several test methods which can be used to evaluate flow of thermoplastic materials. In theory the results from all of these can be reduced to common parameters which can be used in force computation for processing operations. However, this is a very difficult task with non-Newtonian materials. It becomes a much simpler problem if the flow property measurement can be so chosen that the flow pattern is very similar to that in the process being considered. The conditions of shear in rolling and extrusion are very similar; in both cases there exist similar velocity fronts and a finite time under shear. Furthermore, in extrusion plastometer measurements a very wide range of shear rates can be covered. Extrusion plastometry, therefore, is a convenient means of evaluating flow properties for the calculation of roll separating force.

The extrusion test is essentially a capillary flow test in which an apparent viscosity may be determined on the basis of the Poiseuille equation. Separating the relation for viscosity into its two components, shear rate and stress, results in

$$\tau = PR/2L \qquad (2)$$

and

$$S = 4Q/\pi R^3 \qquad (3)$$

where

- τ = shear stress at the capillary wall
- S = shear rate at the capillary wall
- P = pressure difference across the length of the tube
- R = radius of the tube
- L = length of the tube
- Q = volume average rate of flow

In the case of non-Newtonian substances, where the velocity front is not a parabola but follows some power of the radius other than two, Equation (3) does not give the true shear rate. Because of this, and because the viscosity has a separate value at each shear rate value, the viscosity obtained by dividing (3) into (2) is called the apparent viscosity. Such a strictly empirical quantity is useful in all situations in which the velocity front is of the same general form as that found in circular channels.

In addition to the shear rate effect, the time dependent properties of flow must be considered. In extrusion, any element of material is sheared only while it is in the die, and thus for a finite period of time. On a volume average basis this time is the volume of the die divided by the volume rate of discharge. That is

$$\tau(\text{sub } s) = \pi R^2 L/Q$$
$$= (\pi R^3/4Q)(4L/R)$$
$$= 1/S(4L/R) \qquad (4)$$

Thus, the time under shear, τ(sub s), depends on the

Table I
Comparison of Experimental and Computed Bearing Loads on 8 in. x 16 in. Mill

Material	Per Cent Plasticizer (DOP)	Temp. Deg. C.	Separating Force, Pounds Measured	Separating Force, Pounds Computed
Bakelite vinyl resin VYNW + DOP (di-[2- ethylhexyl] phthalate)	30	170	5250	5450
	32	170	4850	4850
	34	170	4450	4300
	36	170	4050	3800
Bakelite Polyethylene Resin DYNH		130	6120	5900
Phenolic Novolak		125	11600	13900

Table II
Computed Separating Forces, F, for Several Calenders

Roll Size, In. (Diameter and Length)	Speed, ft./min.	Thickness (in.)	Material Type	Temp. deg. C.	F, lb.
36 x 92	120	.004	Vinyl + 32 per cent DOP	170	207,000
24 x 66	120	.004	Vinyl + 32 per cent DOP	170	97,000
24 x 66	30	.020	Vinyl + 35 per cent DOP	165	44,000
18 x 48	400	.004	Vinyl + 32 per cent DOP	180	75,000
18 x 48	150	.001	Polyethylene, DYNH	150	91,000

shear rate and the ratio 4L/R. Therefore, adequate allowance for the shear time may be made by expressing the apparent viscosity as a function of shear rate and making an adjustment for the geometric factor 4L/R. Shear-time adjustment factors for plasticized vinyl material and polyethylene have been determined and are reported here for use in roll load calculations. A dimensionless geometric factor for the rolling operation corresponding to that for the extrusion test is derived below.

It should be mentioned that the end effect in an extrusion test may be quite significant when short capillaries are used. This correction comes in as part of the shear-time correction, and it is assumed here that the end effect in calendering is approximately of the same magnitude as that in capillary flow.

Extrusion plastometer measurements have been made to define the flow properties of some typical thermoplastic materials. The apparatus was of the gas-driven type employing compressed nitrogen at a range of pressures to extrude material at various rates through circular dies. The plastometer was patterned after that used by Nason (9). A considerable range of die sizes was available, permitting a number of values of 4L/R. A sample of a commercial grade of polyethylene resin, designated Bakelite polyethylene DYNH, was examined over the temperature range from 130 to 190 deg. C., and a series of plasticized compounds of vinyl chloride-acetate copolymer (Bakelite vinyl resin VYNW) were examined over the temperature range from 160 to 180 deg. C.

Plots of viscosity versus shear rate are shown in Figure 1. The fact that these plots are straight lines over the range covered is convenient but not necessary to the method of treatment. Apparent viscosity is read from this plot at the shear rate applicable to the rolling process. It then must be further corrected to the temperature and shear time of the rolling process, and in the case of the vinyl materials, to the correct plasticizer content. All of these adjustments are made through the use of adjustment factors which, when multiplied by the uncorrected viscosity, yield the required value. That is

$$\eta = \eta^1 \, f(\text{sub s}) \, f(\text{sub t}) \, f(\text{sub p}) \qquad (5)$$

where

η^1 is the uncorrected viscosity (Fig. 1)
f(sub s) is the shear-time adjustment factor
f(sub t) is the temperature adjustment factor
f(sub p) is the plasticizer content adjustment factor

When dealing with polyethylene f(sub p) is dropped from Equation (5).

Figure 2 was constructed from data obtained with various capillaries, and is the same for both materials within reasonable limits. The reference value of 4L/R, the value for the plots in Figure 1, as 30. In order to evaluate the shear-time adjustment when viscosity is to be applied to a rolling process, the geometric factor equivalent to 4L/R must be evaluated for that process. This is done as described in a later section.

Figure 3 shows temperature adjustment factors for the two materials. The reference temperature for the vinyl compounds is 170 deg. C., whereas that for the polyethylene resin is 130 deg. C.

The plasticizer content of a vinyl compound affects the viscosity as shown in Figure 4. The adjustment factor obtained from this plot relates the viscosity to the reference DOP content of 30 per cent.

Mathematical Equations Applied

Because it is readily integrated to give a satisfactory equation for total force, the pressure distribution equation

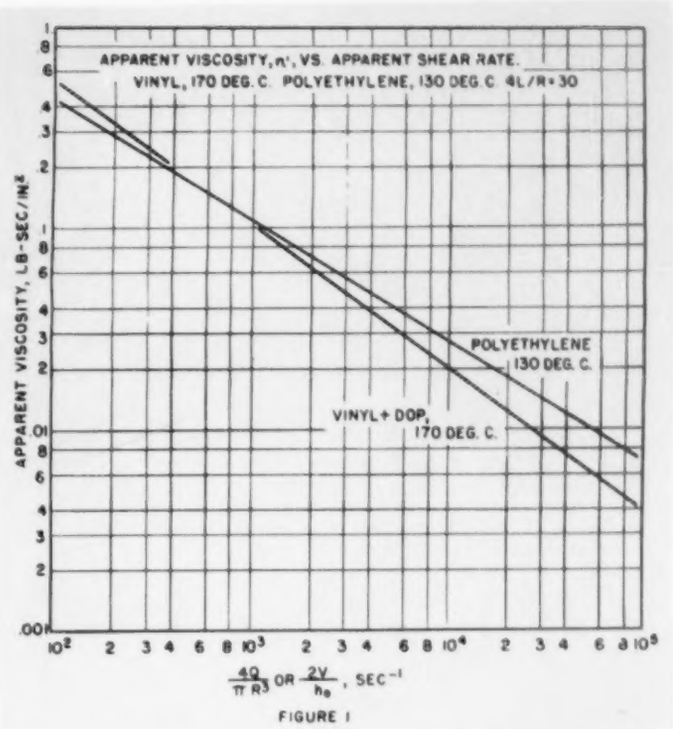

APPARENT VISCOSITY, η', VS. APPARENT SHEAR RATE.
VINYL, 170 DEG. C. POLYETHYLENE, 130 DEG. C. 4L/R = 30
APPARENT VISCOSITY, LB-SEC/IN²
POLYETHYLENE 130 DEG. C.
VINYL + DOP, 170 DEG. C.
4Q/πR³ OR 2V/h₀, SEC⁻¹

FIGURE 1

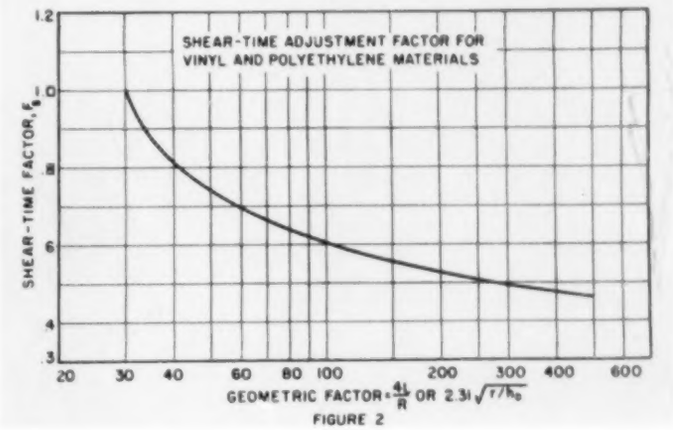

SHEAR-TIME ADJUSTMENT FACTOR FOR VINYL AND POLYETHYLENE MATERIALS
SHEAR-TIME FACTOR, f_s
GEOMETRIC FACTOR = 4L/R OR 2.31√(r/h₀)

FIGURE 2

of Ardichvili is used as the basis for the force calculation. In this section it is shown how the Ardichvili equations, combined with some concepts introduced by Gaskell, are used to derive expressions for apparent shear rate and shear time. These quantities must be evaluated in order to obtain the required apparent viscosity value.

The rolling process and the coordinate systems are illustrated in Figure 5. The point along the x axis of closest approach, where $h = h_n$, is usually named the "nip" or "bite." Because of elastic recovery and because velocity through the nip is greater than roll speed, the material fills the space beyond the nip to a point where $h = h_s$, the magnitude of h_s varying somewhat with material properties and rolling conditions. For a plasticized vinyl material in the 8 in. x 16 in. 2-roll mill at a speed of 28.5 ft./min. it has been observed that the sheet thickness, h_s, was .020 in. when h_n was 0.015 in.

Pressure and shear rate drop to zero as the material passes the point where $h = h_s$. It was pointed out by Gaskell that there is no shear, also, at the point of peak pressure where $h = h_n$. It is evident, therefore, that a

(Please turn to page 40)

Solids Conveying in Extruders

W. H. Darnell and E. A. J. Mol*
E. I. du Pont de Nemours and Co., Inc.

From the standpoint of operation, an extruder screw has three main sections. These are:

a. the feed pickup section.
b. the compression section.
c. the metering section.

The task of each section is to supply the section that follows it with plastic at the rate and in the physical state required by that section. At the delivery end of the machine the last section is the liquid or metering section. In the past the metering section has been the subject of considerable study. The action of the metering section is now well understood on the basis that it is filled with a viscous liquid which wets both the barrel and the screw. We shall limit ourselves in this paper to giving a bibliography of literature on "liquid extrusion" theories (See Appendix I).

The melting or compression section must be able to keep the liquid section which follows it completely filled with molten polymer under all conditions of operation, **i.e.,** at all screw speeds and with dies of widely differing resistances. This is needed for versatility of operation. Sometimes, a considerable part of the melting section becomes liquid-filled, too, and acting as an extruder metering section actually increases the over-all output of the machine. Of course this extra feeding action is a help to the plastics processor but to the screw designer it means that the length term that goes into the output calculations is no longer a constant but depends on the screw speed or the output rate. As the polymer becomes melted earlier in the screw, the length of the liquid section increases, and the output **per rpm** goes up. If the liquid front moves forward, the output per rpm goes down. This interaction between the melting and metering sections is the subject of another paper by E. A. J. Mol, however, so it will not be further discussed here.

The task of the feed section is to pick up and convey to the melting section as solids the quantity of plastic the metering section will extrude after melting has occurred. Thus, the conveying capacity of the feed section must be at least equal to the metering capacity of the liquid section on a weight basis. In the feed section the solid plastic particles, generally in the form of small cubes of more or less regular form, are pushed along by the action of the screw. During this transport the plastic is heated to the point where it begins to soften. The feed section is considered to end where the solids begin melting. The melting and compression zone starts at that point.

In this paper equations will be derived that express the conveying or advancing capacity of the feed section of the extruder screw. These equations should prove useful in designing a screw that will have the correct balance between the delivery rates of the successive sections.

Review of Previous Work

Compared with the amount of work done on the liquid filled sections of a screw, relatively little is known about the solids transport. One of the earliest treatments of the subject is given by Decker (1). The variables which control the solids delivery are discussed. These are the shape and dimensions of the channel, surface temperatures, back pressure, and the coefficient of friction between the plastic and the metal of both the screw and the barrel surface. Though the conclusions given by Decker correlate qualitatively with experience, the formulas given do not relate well to actual behavior. For instance, the possibility of the plastic moving axially only, **i.e.,** without spiraling, is accepted. Without special measures, however, this has never been observed. It is interesting, though, to mention the conclusions of Decker. They are as follows:

1. The friction between the plastic and the screw must be as small as possible. Recommendations: polishing, nickel chrome plating, surface areas as small as possible.

2. The friction between the plastic and the barrel wall must be as large as possible. Recommendations: rough or sanded surface, longitudinal grooves.

3. The lead and profile of the screw must be chosen for the largest axial components of movement and pressure.

4. The "filling factor" or bulk density of the solids must be high.

In 1947 Weber (2) treated the plastic as a solid "nut" but neglected the forces acting between the barrel and the material.

A much more realistic approach to the problem of solids conveying solids in extruders is that given by Pawlowski (3). He considers a balance of forces on the screw contents. The analysis of this balance is based on the estimation of the mechanical forces acting upon the solid plug of plastic from the barrel and screw. The pressures prevailing in the material are included. All forces result in either pressures normal to the flight surface or shearing forces due to friction parallel to the contacting surfaces. The plug as a whole is not regarded as being sheared so the shearing forces result in a torque, thus causing a rotational movement of the plug. This combines with a force component in the axial direction to result in a forward movement of the plug. Pawlowski also mentioned the possibility of a lubrication layer between the plug and the metal surfaces. He can account for this layer by assuming a pressure dependent co-

*Mr. Mol is now with the Rhea Magnet Wire Co., Fort Wayne, Indiana.

(1) Decker, H., "Die Spritzmaschine" (The Extruder), P. Troester, Hanover, Germany (1941).
(2) Weber, F. **Technik** 2, 456 (1947)
(3) Pawlowski, J., unpublished report, Farbenfabriken Bayer, Dormagen, Germany (1949).

efficient of friction.

A more recent attack on the problem of solids feeding was made by Maillefer (4). Maillefer recognized that the problem is one of frictional differentials but his treatment is so simplified that he does not actually solve the problem for a helical channel where torques are involved. He limits himself to a straight channel. Because he did so his results hold only for a very shallow channel. This is not applicable to most feed sections because they must be deep to get economical capacities.

Later, in Appendix II an equation is derived for the conveying rates of solids in an extruder. Maillefer gives an equation for the output of the feed section which is identical with the equation we derive in Appendix II. Included in the conveying rate equation is the angle at which the solids move down the screw channel. We differ from Maillefer, however, in the derivation of a second equation which defines the angle of movement of the solids, which is what really controls the delivery rate. (Our derivation is given in Appendix III.) The equation Maillefer gives can be calculated from screw dimensions, coefficient of friction, and pressure. It looks very simple, but an important force has been overlooked, **i.e.,** the frictional force accompanying the normal force exerted by the moving flight pushing against the plastic plug. Neglecting this frictional force greatly simplifies the solution of the problem but must lead to an incomplete result.

Furthermore, Maillefer formulates as the condition for zero forward movement, no additional pressure build-up. However, this leads to an angle of movement that certainly is not zero. These two conditions cannot exist together. For no forward movement the angle of movement must be zero.

Simonds (5) stresses the importance of friction on solids transport and introduces the balance of torques. Although qualitatively in the right direction, the treatment is much too simplified, and the conclusions are mostly on a "go-or-no-go" basis. That is, the plug either turns with the screw or not. No attempt has been made to calculate the actual forward flow or to include the helix angle in the calculations.

At this point the conclusion must be that definite improvements over the existing theories of solids feeding are needed.

Theory of Plug Flow

In the feed section of an extruder screw both the plastic and the metal are relatively cold, and the plastic does not wet the metal wall. The feed material fills and moves in the helical channel of the screw. We can visualize the material as a confined solid plug which fills the screw channel. The solid plug has the general form of a cork screw. A section of it is sketched in Figure 1. This plug will, when the screw is turning, be subjected to a pushing force normal to the flight surface. Thus it will have a tendency to move off along a helical path, normal to the flight. It will do so when the only resisting forces are the frictional forces on the barrel wall. If these frictional forces were infinite, in the plane normal to the axis, the plug would move along the screw without turning at all, like a nut held in a wrench moves over a turning bolt. As the friction, however, is independent of direction, the nut must turn, **i.e.,** move off perpendicular to the flight surface.

(4) Maillefer, C., Doctorial Thesis, Univ. Lausanne, (1952).

(5) Simonds, H. R., Weith, A. J. and Schack, W., "Extrusion of Plastics, Rubber and Metals," (1952) Reinhold, New York.

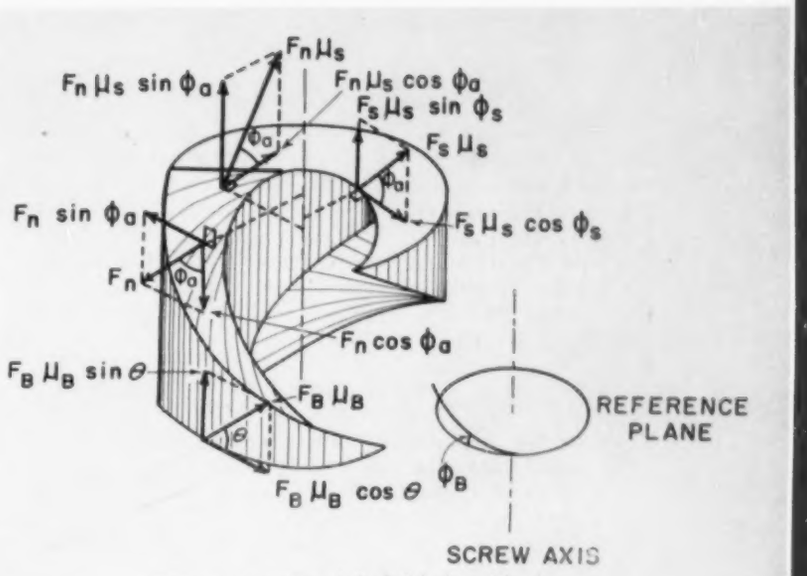


Figure 1. A section of the solid plug of feed

Actually there are also frictional forces trying to drag the plug around with the turning screw. When this happens the forward component of movement of the plug is decreased, the angle of movement diminishes and the delivery rate of the screw drops. Already one very important conclusion from this triple statement of the same fact becomes clear; it is important for solids transport that the screw to plastic contact should have a low coefficient of friction. Carefully machined screw surfaces, highly polished and maintained in this state, are clearly important.

As is the case with virtually all theories we shall have to start with a number of assumptions and limitations. The equations derived from the theory can then be checked against experimental data to see whether or not they fit the facts.

Assumptions. The derivations are based on the following assumptions:

a. The plastic in the screw channel behaves as an "elastic" plug and can have internal pressure.

b. The elastic plug contacts **all** sides of the screw channel, i.e., barrel wall, screw root, and both the pushing and trailing sides of the flight.

c. The pressure may be a constant but may also be a function of the channel length; the initial pressure being P_0 and the delivery pressure P_L.

d. The coefficient of friction between the plastic and the metal surface is independent of pressure.

e. No internal shear takes place. Instead the material behaves as a solid plug. For cube cut materials, if the cube size is greater than one-fourth of the channel depth this assumption will probably not be far off. For smaller particles shear becomes more appreciable.

f. The screw is single-flighted in the feed section; $n = 1$.

g. The width of the flight, **e,** is negligible. A correction will be made later on to allow for the width of the flight.

h. As a consequence of (f) and (g) the width of the screw channel is $w = [(t/n) - e] \cos \phi = t \cos \phi$, where t = lead and ϕ = the helix angle.

i. The radial clearance of the flights, δ, is negligible.

j. The coefficient of friction is the same between the plastic and the screw surface as it is between the plastic and the barrel surface, or $\mu(\text{sub } s) = \mu(\text{sub } B)$. Later on we shall see the effects of having $\mu(\text{sub } s) > \mu(\text{sub } B)$ or $\mu(\text{sub } s) < \mu(\text{sub } B)$.

k. Assume that the weight of the polymer on the barrel and the screw is negligible.

These assumptions help to simplify the derivations. Even so, they lead to fairly complicated equations. More simplifications are possible, but we shall be in a better position to judge their consequences after the derived equations are available.

Delivery Rate. The conveying rate of solids in the feed section of an extruder screw may be calculated from the equation derived in Appendix II

$$Q/N = \frac{\pi^2 D\, h\, (D - h) \tan\theta \tan\phi}{\tan\theta + \tan\phi} \text{ in.}^3\text{/rev.} \qquad (13)$$

where

- θ = the angle of movement of the outer surface of the solid plug, degrees
- ϕ = the helix angle of the screw, degrees**
- h = the depth of the channel, inches
- D = the diameter of the screw and of the barrel, inches**
- N = the rotational speed of the screw, rpm
- Q = volumetric delivery rate of the solids, in.^{3}/min.

Force Balance. In order to estimate the delivery rate by means of Equation (13) it is necessaary to know the value of θ, the angle of the direction of movement of the solid plug relative to a plane perpendicular to the axis of the screw.

Now, θ can be found from the static equilibrium case when the plug is just on the point of moving off in the direction θ. At that time the resultant of all forces on the plug will be zero. Let us therefore consider what forces act on the plug and where. Refer to Figures 1 and 2.

The forces acting are:

F(sub n), the pushing force, normal to the flight surfaces. Its angle with the reference plane (a plane perpendicular to the axis of the screw) is $(90 - \phi)$.

F(sub n) μ(sub s), the frictional force opposing any movement of the plug relative to the screw. Its angle with the reference plane is ϕ (the helix angle), as the plug can only move up or down the channel.

F(sub s) μ(sub s), the frictional force working between the screw root and the inner plug surface caused by the pressure P. This force also opposes relative movement of the plug at an angle of ϕ with the reference plane.

2F(sub f) μ(sub s), the frictional forces on the pushing and trailing sides of the flights caused by the superimposed pressure, P.

F(sub B) μ(sub B), the frictional force between the plug and the barrel, also caused by the pressure P, but working under the angle of movement θ with the reference plane.

The directions of the frictional forces, F(sub n) μ (sub s) and F(sub s) μ(sub s), are determined solely by the form of the screw because the plug can only follow the flight. The barrel friction, F(sub B) μ(sub B), however, can have any direction, but it is always one exactly opposing the direction of movement of the plug.

These forces must be balanced. They can be resolved into their components, those acting perpendicular to the reference plane and those acting parallel to the reference plane. The forces parallel to the screw axis can be added algebraically; they are all acting along the same line of force. The components in the reference plane act on cylindrical surfaces, however, and have to be treated as torques, each force working on its own lever arm. At the barrel surface the lever arm is D/2. For the screw root [F(sub s)] it is (D — 2h)/2. For the forces on the flight surfaces, F(sub n), F(sub n) μ(sub s), and F(sub f)-

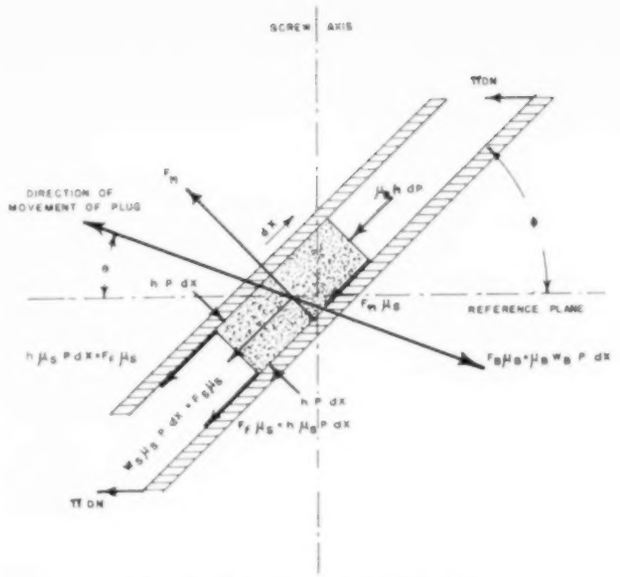


Figure 2. Forces acting on solids plug

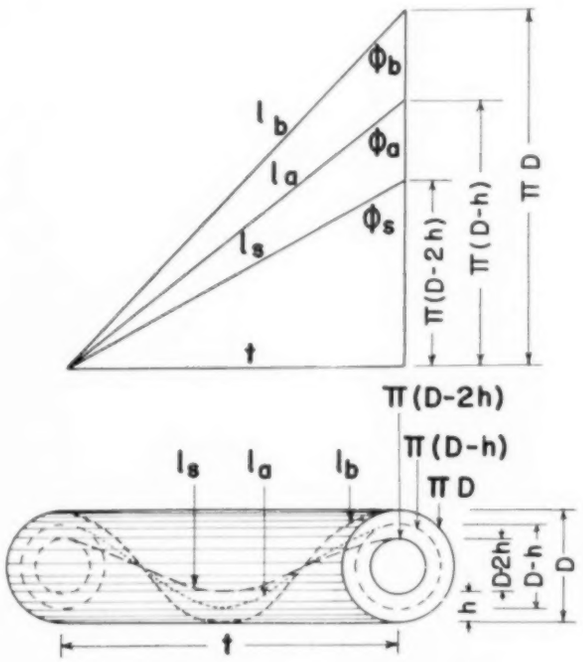


Figure 3. Trigonometrical Relationships

$$\tan\phi_B = \frac{t}{\pi D} \qquad \sin\phi_B = \frac{t}{l_B} \qquad \cos\phi_B = \frac{\pi D}{l_B}$$

$$\tan\phi_a = \frac{t}{\pi(D-h)} \qquad \sin\phi_a = \frac{t}{l_a} \qquad \cos\phi_a = \frac{\pi(D-h)}{l_a}$$

$$\tan\phi_s = \frac{t}{\pi(D-2h)} \qquad \sin\phi_s = \frac{t}{l_s} \qquad \cos\phi_s = \frac{\pi(D-2h)}{l_s}$$

with $E = \frac{D-h}{D}$ and $C = \frac{D-2h}{D}$; $\tan\phi_B = E\tan\phi_a = C\tan\phi_s$

**ϕ and D written without a subscript are understood to be ϕ(sub B) and D(sub B).

μ(sub s), an intermediate value is needed. To simplify matters an average lever arm, (D — h)/2, will be used.

The helix angle of the flight surface increases as we move inward to the screw root. The force components of the forces working on the flight surface parallel to and perpendicular to the reference plane have to be calculated with these local helix angles. Again for simplification, let us introduce an average helix angle, ϕ(sub a). This angle is defined by tan ϕ(sub a) = [tan ϕ(sub B)]/E where E = (D — h)/D. (These and other relationships are given in Figure 3.) The errors introduced by these simplifications are negligible.

After there preliminaries we can now write the balance of forces perpendicular to the reference plane and the balance of moments parallel to the reference plane. In Appendix III these balances have been written. The forces are diagrammed in Figures 1 and 2.

The forces F(sub s), F(sub B), and F(sub f) are the products of the prevailing pressure P and the surface, offered by the length of the plug under consideration. This length is measured along the channel itself. The forces F(sub n), F(sub s), and F(sub f) obtain the values given in Equations (15) and (20) of Appendix III. Substituting and collecting terms results in the equations

$$dF(\text{sub n})\ [(\cos \phi(\text{sub a}) - \mu(\text{sub s}) \sin \phi(\text{sub a})] = A_1 P dx + A_2 dp \tag{19}$$

$$df(\text{sub n})\ [(E \sin \phi(\text{sub a}) + E\,\mu(\text{sub s}) \cos \phi(\text{sub a})] = B_1 P dx - B_2 dp \tag{25}$$

Letting K be the ratio of the forces acting perpendicular to the reference plane to those acting parallel

$$(27)\quad K = \frac{E(\sin \Phi_a + \mu_s \cos \Phi_a}{\cos \Phi_a - \mu_s \sin \Phi_a} = \frac{B_1 P dx - B_2 dP}{A_1 P dx + A_2 dP}$$

leads to the differential equation

$$K(A_1 P dx + A_2 dp) = B_1 P dx - B_2 dP \tag{28}$$

which is not too difficult to solve. Finally we end up with

$$(40)\quad \cos\Theta = K \sin\Theta + C\left(K \sin\phi_s + C \cos\phi_s\right) + \frac{2h}{t}\left(KC \tan\phi_s + E^2\right) + \frac{hE}{L\mu_B} \sin\phi_a \left(E \cos\phi_A + K \sin\phi_a\right) \ell n \frac{P_2}{P_1}$$

Discussion of Equations

By careful scrutiny of the equation just developed some useful information can be gained. By letting M stand for the last three terms of Equation 40 the following shortened equation is obtained:

$$\cos \theta = K \sin \theta + M \tag{41}$$

The simplest way to visualize this equation is to plot M as a function of K with θ as a parameter. This has been done in Figure 4. From this graph it is easy to deduce that for the largest angle of movement, and hence the largest transport of solids, both K and M should be small. A small M implies a small K, E, and C. For the latter two of these this means a deep screw channel.

No Forward Movement. The condition for no forward movement is also directly apparent from Equation 41. When the angle of movement θ, is zero the extruder screw is not conveying solids. For θ = 0; sin θ = 0; cos θ = 1; and therefore M = 1.

Effect of Back Pressure. The constant M, consists of three parts.

$$(42)\quad M = C\left(K \sin\phi_s + C \cos\phi_s\right) + \frac{2h}{t}\left(KC \tan\phi_s + E^2\right) + \frac{hE}{L\mu_B} \sin\phi_a \left(E \cos\phi_A + K \sin\phi_a\right) \ell n \frac{P_2}{P_1}$$

The last term, containing ln P_2/P_1, represents the influence of back pressure on output. Note that for a given ϕ and h, ln P_2/P_1 is proportional to μ(sub B) and L. Any increase in the length of surface over which the friction acts helps to greatly increase the pressure that can be overcome. Remember, however, that K is also dependent on μ(sub B). When $P_2 = P_1$, this item becomes zero, M becomes smaller, and the delivery rate increases. One can also estimate at what back pressure the delivery will stop altogether. That is when the value of the pressure P_2 is enough greater than P_1, that M equals 1.

No Contact with Trailing Flight. The middle term of M represents the contribution of the screw flights. When there is no contact with the trailing flight, the forces resulting from pressure must be modified because there is contact pressure only in radial directions. When this is done, the last two terms of M and of Equation 40 drop out and Equation 40 reduces to

$$\cos \theta = K \sin \theta + C[(K \sin \phi(\text{sub s}) + \cos \phi(\text{sub s})] \tag{43}$$

For the simple case represented by Equation 43, let us see how the angle of movement, θ, depends upon the helix angle, ϕ, and the coefficient of friction, μ(sub s). We can do this by considering how K varies with ϕ and μ(sub s). Recall that μ(sub s) enters Equation 43 by means of the definition of K which is:

$$(27)\quad K = \frac{E(\sin \Phi_a + \mu_s \cos \Phi_a)}{\cos \Phi_a - \mu_s \sin \Phi_a}$$

By substituting the relationships shown in Figure 3, K may be also written as

$$(44)\quad K = \frac{E(\tan \Phi_a + \mu_s)}{1 - \mu_s \tan \Phi_a}$$

In Figure 5, K has been plotted as a function of ϕ(sub a) with μ(sub s) as a parameter for E values of 0.80 and 0.90. From the graph it is obvious that small values of ϕ and low μ(sub s) both lead to a small K. It is desirable for K to be small to increase θ, the angle of movement. Also note that K is smaller at lower values of E. This again implies that better transport is obtained with deep screws. This last statement must be made with reservation, however, because along with a smaller E goes a higher helix angle at the root of the screw, ϕ(sub s). In the range of helix angles in which we are interested, though, a deeper channel will lead to a lower over-all value for M.

Differences in Coefficients of Friction. In making the derivation given in Appendix III we assumed (right after Equation 33) that the coefficient of friction of the plastic on the screw channel, μ(sub s), was equal to the coefficient of friction of the plastic on the extruder barrel, μ(sub B). This step was taken to greatly reduce the complexity of the equations obtained. In actual practice, however, this is generally not true. Had this assumption not been made, then the terms now represented by C and E would have had to contain, also, the ratio μ(sub s)/μ(sub B). Then to make the value of C or E small (to make M small, θ large and the conveying capacity high) the coefficient of friction on the screw, μ(sub s), should be low and the coefficient of friction on the barrel, μ(sub B), should be high. Experimental results given later illustrate the effect of the μ(sub s)/μ(sub B) ratio.

No friction on Screw. Now let us look at what would happen if the friction of the plastic on the screw were so low that it could be considered to be zero. This might be thought of as the best theoretically possible case. When μ(sub s) = 0 and $P_1 = P_2$ we can see in Equation 39 that all terms except the first one drop out, and that K, which is given by Equation 44, reduces to E tan

Figure 4. Plot of M as a function of K, with θ as a parameter

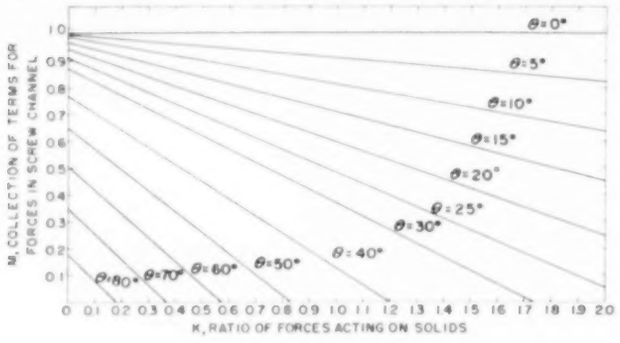


Figure 5. Plot of K as a function of Φ (sub a) with μ (sub s) and E as parameters

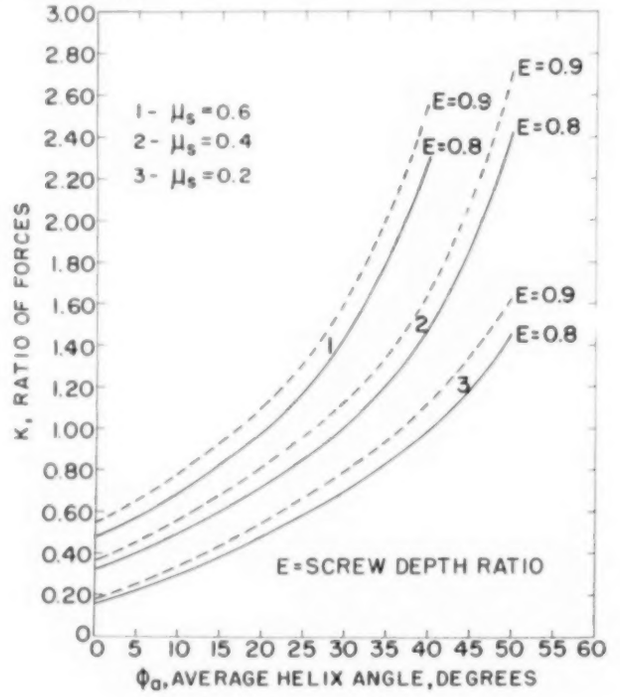
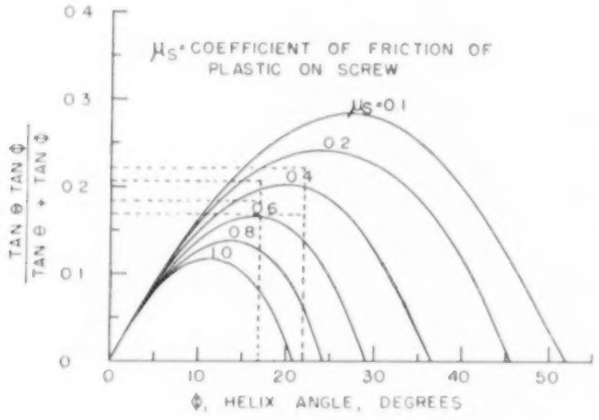


Figure 6. Typical Feed Screw-tan function plotted against helix angle.



ϕ(sub a), which is equal to tan ϕ(sub B). in this case:

$$\cos \phi = K \sin \phi \quad (45)$$

and

$$\cos \theta / \sin \theta = \cot \theta = K = \tan \phi(\text{sub B}) \quad (46)$$

Making substitutions into Equation 13, the delivery rate equation, reduces it to:

$$Q/N = \pi^2 D h (D - h) \sin \phi \cos \phi \quad (47)$$

In the symposium on the theory of plastics extrusion (6) the drag flow capacity of the metering section of an extruder screw when pumping a fluid melt is given as:

$$Q/N = \tfrac{1}{2} \pi^2 (D - h)^2 h \sin \phi \cos \phi \quad (48)$$

Note that the right side of Equation 47 is about twice that of Equation 48. This implies that in a given screw the volumetric delivery rate for solids is about twice the volumetric drag flow capacity for liquid melts. Of course, the bulk density of a solids feed is never equal to the liquid density. In fact it is seldom more than 0.5-0.7 of it. With absolutely no friction between plastic and screw and no back pressure, we might infer that the maximum delivery rate of the feed section on a weight basis thus is about equal to the drag flow capacity for the melt. But even a slight increase in friction on the screw drastically reduces the solids feed delivery rate, for most plastics, below the liquid drag flow capacity. With little or no back pressure on the delivery end of the machine a compression ratio of from about 2.5 for polyethylene to about 4.0 for "Lucite" acrylic resin is necessary, depending upon the helix angle. If the compression ratio is not high enough, the metering section of the screw is starved when it is being operated at or near to open discharge. The machine output is then controlled by the feed section. The delivery rate may become irregular because changes in bulk density and friction (due to small temperature variations) are immediately reflected in the delivery rate.

It might be interesting to note at this point that a British patent (7) has just been issued for coating an extruder screw with polytetrafluoroethylene to give a low coefficient of friction and improve the efficiency of feeding.

Maximum Delivery. What are the conditions which favor a maximum delivery by the feed section of the extruder screw? We have seen that the following conditions favored a large angle of movement:

a. A deep screw.
b. A low coefficient of friction on the screw, μ(sub s).
c. A high coefficient of friction on the barrel, μ(sub B).
d. A small helix angle, ϕ.

Although it is true that having a small helix angle will increase the angle of movement, θ, it is not necessarily true that the output, Q/N, will increase. This happens because the actual delivery rate, which is given by Equation 13,

$$(13) \quad \frac{Q}{N} = \frac{\pi^2 D h (D-h) \tan \Theta \tan \phi}{\tan \Theta + \tan \phi}$$

is a function of both ϕ and θ. When ϕ is at a minimum θ is at a maximum and conversely. At both these extremes Q/N = 0. It is clear that somewhere in between there is a value of ϕ where Q/N is a maximum. This helix angle of maximum delivery rate depends on the difference of friction as does the magnitude of the maximum delivery rate itself. For a low coefficient of friction between the plastic and the screw, ϕ(max) and Q/N are large.

(6) Carley, J. F., Strub, R. A., Mallouk, R. S., McKelvey, J. M., and Jepson, C. H., "Symposium on the Theory of Plastics Extrusion," Ind. Eng. Chem., 45, 969-993 (1953).
(7) Caun, J. R., British 715,920

For example, a screw, working well for acrylics will always work equally well or better for polyethylene, but the reverse is not true. In fact, the best feed section for polyethylene may have a very low capacity for acrylics. This can be deduced at a glance from Figue 6 where the function (tan θ tan ϕ)/(tan θ + tan ϕ) is plotted against the helix angle ϕ for a typical screw for several values of μ(sub s). The calculations upon which the curves in Figure 6 are based are shown in Appendix IV. If μ(sub s) = 0, the position of ϕ(max) would be at 45°. This corresponds to the point where the function sin ϕ cos ϕ is a maximum. If μ(sub s) is not zero, the helix angle of maximum output, ϕ(max), shifts to a smaller value. For μ(sub s) = 0.25-0.40, as for polyethylene ϕ(max) is about 22°. For μ(sub s) = 0.40-0.60, as for acrylics, ϕ(max) is about 17°.

The general conclusion is that for safe, dependable delivery of plastics of various coefficients of friction the helix angle should not be too large (not over 17.7° or the lead = diameter) and the channel should not be shallow.

Experimental Verification

To test the validity of the foregoing theory some experiments on solids feeding were carried out. Three extruder screws which had a uniform channel depth throughout were constructed. The dimensions of these screws are shown in Table I. The screws were tested in regular metal extruder barrels at 25°C. For observing the feeding action the screws were also operated in a barrel made of "Lucite."

Calculated Expected Conveying Rates

In Appendix V the conveying rates to be expected for these screws are computed for several common plastic resins.

Experimental Data

In Table II the average conveying rates found experimentally for these resins are compared with the calculated rates.

Discussion of Results

In making a comparison of the theoretical and experimental outputs of the feed zone of an extruder screw several factors manifest their importance. These factors are (1) the variation of the rate of solids conveying with time, (2) the bulk density of the resin, and (3) the coefficient of friction of the resin on the barrel and screw surfaces.

In Table II each conveying rate reported is an average of 10 to 70 observations. In given one-minute intervals the conveying rates were observed in a few instances to be as much as 15% above or below the average. When we watched the feeding of plastics resins by the extruder screw in the "Lucite" barrel, the reasons for the fluctuations became apparent. As the screw turns the particles do not always advance in one direction and in a uniform manner. Sometimes they tumble, slide, bind, or bridge in the screw channel. Occasionally it could be observed that the solids were turning with the screw. At another moment the particles might tumble to the bottom of the screw channel and be pushed forward sharply by the advancing screw flight. At other times several particles would stack themselves one upon the other to make a pillar the height of the screw channel. Then a wedge of other particles would dam up behind this pillar until enough force was exerted to cause the pillar to fall. As in any occurrence that varies in a random manner the average serves as a representative value of the process taken as a whole. Similarly, our original concept of the solids particles acting as an elastic plug is probably a representative picture although at a given instant some tumbling, or bridging, or other random motion of the individual particles might make it invalid.

In making the computations shown in Appendix V it is necessary to know values of the bulk density and of the coefficient of friction of the resin. Because of the size and shape of the pellets the bulk densities of common plastics resins are dependent upon the size and geometry of the container in which they are measured. As shown in Table III, in small graduated cylinders the bulk density is lower than in large ones. To approximate the size and shape of extruder channels, rectangular boxes of various widths and depths were constructed. These were filled with resin and a straight edge was scaped across the top to approximate the action of the extruder barrel in passing over the screw channel. Some of the bulk densities determined in this manner are reported in Table IV. It was found that the bulk density is independent of channel width but decreases with a decrease in depth. We should expect this to be so because the width of the channel is much greater than the par-

TABLE I

Dimensions of Experimental Feed Screws

	Screw A	Screw B	Screw C
Diameter, inches	1.991	1.960	1.960
Root diameter, inches	1.375	1.00	1.00
Lead, inches	2.000	2.70	2.29
Land width, inches	0.200	0.125	0.125
Helix angle, degrees	17.7	23.7	20.0

TABLE II

Conveying Rate of Plastics

	Average Conveying Rates, gm./rev.		
	"Zytel" 101 Nylon Resin	"Alathon" 10 Polyethylene	"Lucite" 140 Acrylic Resin
Screw A			
Calculated Rate	14.4	13.0	15.3
Smooth Barrel, μ(sub B) $\simeq$ μ(sub s)	14.9	13.2	13.5
Rough Barrel, μ(sub B) $>$ μ(sub s)	—	15.8	23.2
Polished Barrel, μ(sub B) $<$ μ(sub s)	11.4	—	12.1
Screw B			
Calculated Rate	26.5	23.2	25.3
Smooth Barrel, μ(sub B) $\simeq$ μ(sub s)	24.3	21.1	24.3
Rough Barrel, μ(sub B) $>$ μ(sub s)	—	—	27.9
Polished Barrel, μ(sub B) $<$ μ(sub s)	18.1	19.2	—
Screw C			
Calculated Rate	25.4	23.2	26.3
Smooth Barrel, μ(sub B) $\simeq$ μ(sub s)	22.0	23.1	28.9
Rough Barrel, μ(sub B) $>$ μ(sub s)	24.4	24.8	32.9
Polished Barrel, μ(sub B) $<$ μ(sub s)	20.9	—	24.3

ticle size but the channel depth is not. It made no difference at what angle the straight edge passed over the channel. Any particles which protruded partially above the top of the channel were swept away by the moving edge. This left the channel with some unfilled space. The bulk density determined in this manner is probably too low because there was no opportunity for the particles to fall into and completely fill some portion of the channel at a lower elevation. In filling the channel of an extruder screw the particles fall loosely and freely on one another and there is some, but not much, opportunity for packing to take place. Thus, the bulk density of the material in the channel of a rotating screw would be expected to be lower than in a graduate and higher than in a shallow rectangular box. In order to estimate the dynamic bulk density of the material in an extruder screw we ran screw A for a period of time and then stopped and pulled the screw, being careful to catch the contents from a measured length of the screw. The average of ten measurements made in this manner in screw A for each resin is reported in Table V. Here again the variations that occur with time play a part and limit the accuracy of the determinations.

For coefficient of friction measurements most investigators report that it is difficult to get reproducible results. Another complication we find is that most investigators fail to specify the surface finish. It is known that the coefficients of friction on micropolished steel are ½ to ⅓ those on ordinary polished steel. The values which follow are for ordinary steel. Gebhard (8) has found that at room temperature the dynamic coefficient of friction for nylon on steel is about 0.25 and for "Lucite" on steel is about 0.14. For "Kralastic" B he reports 0.25 and for "Kralastic" F, 0.27. Spencer (9) reported a coefficient of 0.215-0.239 for Saran. Roche (10) gives 0.248 for polystyrene. Shooter (11) gives the following values of coefficient of sliding friction at room temperature for ordinary polished steel:

"Teflon" tetrafluoroethylene resin on steel: 0.04
"Teflon" on "Teflon": 0.04
Polyethylene on steel: 0.15
Polyethylene on polyethylene: 0.10
Polystyrene on steel: 0.30
Polystyrene on polystyrene: 0.5*
"Perspex" (polymethylmethacrylate) on steel: 0.5*
"Perspex" on "Perspex": 0.8*

*Intermittent motion.

In a later reference Shooter (12) gives:

Polyvinyl chloride on steel: 0.5
Polyvinyl chloride on polyvinyl chloride: 0.4-0.6
Polyethylene on steel: 0.25
Polyethylene on polyethylene: 0.25
Polystyrene on steel: 0.4-0.5
Polystyrene on polystyrene: 0.4-0.5
Polymethylmethacrylate on steel: 0.5
Polymethylmethacrylate on polymethylmethacrylate:: 0.4-0.6
Nylon on steel: 0.25
Nylon on nylon: 0.25

Shooter (12) points out that at loads of 100 to 10,000 grams the coefficient of friction is constant, but at lighter loads it generally increases.

Faced with making a decision as to what values of the coefficient of friction to use for the calculations shown in Appendix V we chose the following values:

"Zytel" 101 nylon resin	0.25
"Alathon" 10 polyethylene	0.40
"Lucite" 140 acrylic resin	0.50

The value of 0.40 for polyethylene is higher than the 0.25 suggested by Shooter (12). The higher value was

(8) Gebhard, J. C., Jr., Private communication, November 11, 1954.
(9) Spencer, R. S., Gilmore, G. D. and Wiley, R. M., **J. App. Physics**, 21, 527-531 (1950).
(10) Roche, A. F., unpublished data. Cited in reference (7).
(11) Shooter, K. V. and Thomas, P. H., **Research**, 2, 533-535 (1949).
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TABLE III
Bulk Densities of Plastics Resins as Determined in Graduates

Material	Graduate Volume, cc.	Bulk Density gm./cc.
"Zytel" 101 nylon resin	1000	0.58
	500	0.58
	250	0.58
	100	0.54
	50	0.53
	10	0.45
"Alathon" 10 polyethylene	1000	0.51
	500	0.51
	250	0.54
	100	0.51
	50	0.51
	10	0.42
"Lucite" 140 acrylic resin	1000	0.63
	500	0.63
	250	0.63
	100	0.62
	50	0.62
	10	0.55

TABLE IV
Bulk Densities of Plastics Resins as Determined in Shallow Rectangular Boxes

Material	Height of Box, Inches	Bulk Density, gm./cc.
"Zytel" 101 nylon resin	1.0	0.48
	0.75	0.45
	0.50	0.38
	0.375	0.17
"Alathon" 10 polyethylene	1.0	0.45
	0.75	0.43
	0.50	0.39
	0.375	0.33
	0.25	0.14
"Lucite" 140 acrylic resin	1.0	0.55
	0.75	0.51
	0.50	0.45
	0.375	0.38

TABLE V
Average Dynamic Bulk Densities of Plastics Resins (As Determined in Screw A)

Material	Dynamic Bulk Density gm./cc.
"Zytel" 101 nylon resin	0.475
"Alathon" 10 polyethylene	0.490
"Lucite" 140 acrylic resin	0.613

chosen because we found in making calculations that using 0.25 gave predicted outputs that were about 11-12% higher.

Now let us compare the measured feeding rate of the three screws given in Table II with the predicted rates. For the smooth barrel we see that the agreement is generally good. This barrel was machined to about the same smoothness as were the three experimental feed screws. For the smooth barrel the coefficient of friction of the resin on the barrel was probably about the same as that of the resin on the screw, i.e., $\mu_B = \mu_s$, which is the assumption made in calculating the predicted conveying rates.

For the rough barrel, which was scored and pitted, μ_B was undoubtedly greater than μ_s and the measured rates were higher than predicted.

The third barrel was a new barrel in a commercial extruder and had a mirror-like finish that was smoother than the machine finish on the experimental screws. For this barrel μ_B was less than μ_s and the observed conveying rates were lower than predicted.

Thus we can see that for good feeding of plastics resins it is important to keep the extruder screw at least as smooth, if not smoother, than the extruder barrel.

Considering the uncertainties in the values of the coefficients of friction, and of the bulk densities of plastics resins and the variation of output with time, it appears that the equations developed give good estimates of the output to be expected for extruder screws. It is hoped and anticipated that these equations will prove useful in the design of extruder screws.

Appendix I

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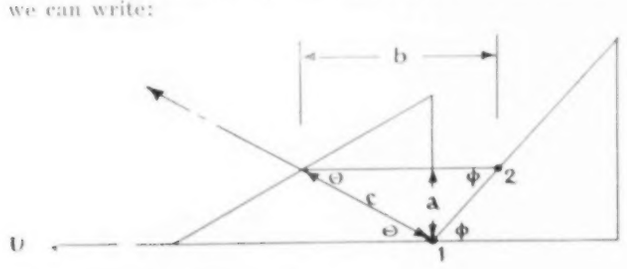
Appendix II

DERIVATION OF DELIVERY RATE EQUATION

Let τ = the time for the solid plug to slide from position 1 to position 2 along the top of the screw channel when the peripheral velocity of the screw is U. Then

$$\tau = b/U) \tag{1}$$

From the geometric relationships shown in the sketch we can write:



$$V_x = \frac{a}{\tau} = \frac{c \sin\Theta}{\tau} = \frac{U c \sin\Theta}{b} \tag{2}$$

by the Law of Sines

$$\frac{c}{b} = \frac{\sin\phi}{\sin\left[180-(\Theta+\phi)\right]} \tag{3}$$

$$V_x = \frac{U \sin\Theta \sin\phi}{\sin\left[180-(\Theta+\phi)\right]} = \frac{U \sin\Theta \sin\phi}{\sin(\Theta+\phi)} \tag{4}$$

by identity

$$\sin(\Theta+\phi) = \sin\Theta\cos\phi + \sin\phi\cos\Theta \tag{5}$$

$$V_x = \frac{U \sin\Theta \sin\phi}{\sin\Theta\cos\phi + \sin\phi\cos\Theta} \tag{6}$$

Dividing top and bottom by cos θ cos ϕ gives

$$V_x = \frac{U \tan\Theta \tan\phi}{\tan\Theta + \tan\phi} \tag{7}$$

$$Q = \frac{\pi}{4}\left[D^2 - (D-2h)^2\right] V_x \tag{8}$$

$$Q = \pi h (D-h) V_x \tag{9}$$

$$Q = \frac{\pi h (D-h) U \tan\Theta \tan\phi}{\tan\Theta + \tan\phi} \tag{10}$$

Now $U = \pi DN$, so (11)

$$Q = \frac{\pi^2 DhN(D-h) \tan\Theta \tan\phi}{\tan\Theta + \tan\phi} \tag{12}$$

$$\frac{Q}{N} = \frac{\pi^2 Dh(D-h) \tan\Theta \tan\phi}{\tan\Theta + \tan\phi} \tag{13}$$

Appendix III

FORCE BALANCE EQUATIONS

Refer to Figures 1 and 2.

See Table of Nomenclature for terms not defined elsewhere.

The pressure drop over distance dx is dP. In the summation both, h P dx, pressures against the walls (flight surfaces) can be omitted, because they neutralize each other. This is not so for the frictional forces caused by these pressures, because they work in opposite directions. **Forces acting perpendicular to the reference plane(parallel to the screw axis).**

$$\sum dF_z = -dF_n\cos\phi_a + dF_B\sin\Theta + 2dF_f\mu_s\sin\phi_a + dF_n\mu_s\sin\phi_a + dF_s\mu_s\sin\phi_s + w_a h\sin\phi_a dP = O \tag{14}$$

$$\sum dF_x = -dF_n\cos\phi_a + \mu_B w_B\sin\Theta P dx + 2h\mu_s\sin\phi_a P dx + dF_n\mu_s\sin\phi_a + w_s\mu_s\sin\phi_s P dx + w_a h\sin\phi_a dP = O \tag{15}$$

Collecting terms:

$$\sum dF_x = dF_n\left(-\cos\phi_a + \mu_s\sin\phi_a\right) + P dx\left(\mu_B w_B\sin\Theta + 2h\mu_s\sin\phi_a + w_s\mu_s\sin\phi_s\right) + w_a h\sin\phi_a dP = O \tag{16}$$

Let:

$$A_1 = \mu_B w_B\sin\Theta + 2h\mu_s\sin\phi_a + w_s\mu_s\sin\phi_s \tag{17}$$

$$A_2 = w_a h\sin\phi_a \tag{18}$$

Then:

$$dF_n\left(\cos\phi_a - \mu_s\sin\phi_a\right) = A_1 P dx + A_2 dP \tag{19}$$

Forces acting parallel to the reference plane (perpendicular to the screw axis) are to be counted as torques.

$$\sum My = -dF_n\sin\phi_a E + \mu_B w_B\cos\Theta P dx - 2h\mu_s\cos\phi_a E P dx - dF_n\mu_s\cos\phi_a E - w_s\mu_s\cos\phi_s C P dx - w_a h E\cos\phi_a dP = O \tag{20}$$

where:

$$E = \frac{D-h}{D} \; ; \; C = \frac{D-2h}{D} \tag{21}$$

Collecting terms:

$$dF_n\left(E\sin\phi_a + E\mu_s\cos\phi_a\right) = Pdx\left(\mu_B w_B\cos\Theta - 2h\mu_s\cos\phi_a E - w_s\mu_s\cos\phi_s C\right) - w_a hE\cos\phi_a dP \tag{22}$$

Let:

$$B_1 = \mu_B w_B\cos\Theta - 2h\mu_s\cos\phi_a E - w_s\mu_s\cos\phi_s C \tag{23}$$

$$B_2 = w_a hE\cos\phi_a \tag{24}$$

Then:

$$dF_n\left(E\sin\phi_a + E\mu_s\cos\phi_a\right) = B_1 Pdx - B_2 dP \tag{25}$$

Now, let:

$$K = \frac{dF_n\left(E\sin\phi_a + E\mu_s\cos\phi_a\right)}{dF_n\left(\cos\phi_a - \mu_s\sin\phi_a\right)} \tag{26}$$

$$K = \frac{E\left(\sin\phi_a + \mu_s\cos\phi_a\right)}{\cos\phi_a - \mu_s\sin\phi_a} = \frac{B_1 Pdx - B_2 dP}{A_1 Pdx + A_2 dP} \tag{27}$$

whence:

$$K\left(A_1 Pdx + A_2 dP\right) = B_1 Pdx - B_2 dP \tag{28}$$

dividing by P and collecting terms:

$$\left(KA_1 - B_1\right)dx = -\left(B_2 + KA_2\right)\frac{dP}{P} \tag{29}$$

integrating over l:

$$\int_0^l \left(KA_1 - B_1\right)dx = -\int_{P_1}^{P_2}\left(B_2 + KA_2\right)\frac{dP}{P} \tag{30}$$

gives

$$\left(KA_1 - B_1\right)l = -\left(B_2 + KA_2\right)\ln\frac{P_2}{P_1} \tag{31}$$

Now, substituting for A_1 and B_1, and adding the appropriate subscripts on l. (Refer to Figure 3.)

$$l_B K\mu_B w_B\sin\Theta + l_a K 2h\mu_s\sin\phi_a + l_s K w_s\mu_s\sin\phi_s - l_B\mu_B w_B\cos\Theta + l_a 2h\mu_s\cos\phi_a E + l_s w_s\mu_s\cos\phi_s C + \left(B_2 + KA_2\right)\ln\frac{P_2}{P_1} = 0 \tag{32}$$

Solving for cos θ and separating terms:

$$\cos\Theta = \frac{l_B K\mu_B w_B\sin\Theta}{l_B\mu_B w_B} + \frac{l_a K 2h\mu_s\sin\phi_a}{l_B\mu_B w_B} + \frac{l_s K w_s\mu_s\sin\phi_s}{l_B\mu_B w_B} + \frac{l_a 2h\mu_s\cos\phi_a E}{l_B\mu_B w_B} + \frac{l_s w_s\mu_s\cos\phi_s C}{l_B\mu_B w_B} + \frac{\left(B_2 + KA_2\right)\ln\frac{P_2}{P_1}}{l_B\mu_B w_B} \tag{33}$$

Assuming μ(sub B) = μ(sub s) and making the substitutions:

$$w_s = t\cos\phi_s \; ; \; w_B = t\cos\phi_B \tag{34}$$

$$l_a = \frac{L}{\sin\phi_a} \; ; \; l_s = \frac{L}{\sin\phi_a} \; ; \; l_B = \frac{L}{\sin\phi_a} \tag{35}$$

gives:

$$\cos\Theta = K\sin\Theta + \frac{2hK}{t}\left(\frac{\sin\phi_B}{\cos\phi_B}\right) + K\cos\phi_s\left(\frac{\sin\phi_B}{\cos\phi_B}\right) + \frac{2hE}{t}\left(\frac{\cos\phi_a}{\sin\phi_a}\right)\left(\frac{\sin\phi_B}{\cos\phi_B}\right) + C\left(\frac{\cos\phi_s}{\sin\phi_s}\right)\cos\phi_s\left(\frac{\sin\phi_B}{\cos\phi_B}\right) + \frac{\left(B_2 + KA_2\right)\ln\frac{P_2}{P_1}}{l_B\mu_B w_B} \tag{36}$$

$$\cos\Theta = K\sin\Theta + \frac{2hK}{t}\tan\phi_B + K\cos\phi_B\tan\phi_B + \frac{2hE}{t}\cot\phi_a\tan\phi_B + C\cot\phi_s\cos\phi_s\tan\phi_B + \frac{\left(B_2 + KA_2\right)\ln\frac{P_2}{P_1}}{l_B\mu_B w_B} \tag{37}$$

substituting:

$$\tan\phi_B = E\tan\phi_a = C\tan\phi_s \tag{38}$$

gives

$$\cos\Theta = K\sin\Theta + \frac{2h}{t}KC\tan\phi_s + KC\sin\phi_s + \frac{2h}{t}E^2 + C^2\cos\phi_s + \frac{\left(B_2 + KA_2\right)\ln\frac{P_2}{P_1}}{l_B\mu_B w_B} \tag{39}$$

Making similar substitutions for B_2 and A_2 gives:

$$\cos\Theta = K\sin\Theta + C\left(K\sin\phi_s + C\cos\phi_s\right) + \frac{2h}{t}\left(KC\tan\phi_s + E^2\right) + \frac{hE}{L\mu_B}\sin\phi_a\left(E\cos\phi_a + K\sin\phi_a\right)\ln\frac{P_2}{P_1} \tag{40}$$

Appendix IV

CALCULATIONS FOR FIGURE 6

Assume the following as the dimensions of the feed section of a typical screw.

D = 2.000 in.

h = 0.400 in.

C = (D − 2h)/D = 0.6

E = (D − h)/D = 0.8

The value of K is calculated from Equation 44.

$$K = \frac{E\left(\tan\phi_a + \mu_s\right)}{1 - \mu_s\tan\phi_a} \tag{44}$$

Figure 7 is a design chart which gives values of

$$\frac{\tan\phi_a + \mu_s}{1 - \mu_s\tan\phi_a}$$

for various values of φ(sub a) and μ(sub s). Multiplying values of this function read from the chart by E gives K.

The relationships of φ(sub B), φ(sub s), φ(sub a) are given in Figure 3.

The value of θ was obtained by solving Equation 43, which was assumed to be applicable in this case.

$$\cos\theta = K\sin\theta + C\left[K\sin\phi(\text{sub s}) + C\cos\phi(\text{sub s})\right] \tag{43}$$

Figure 4 is a design chart which was used in solving Equation 43.

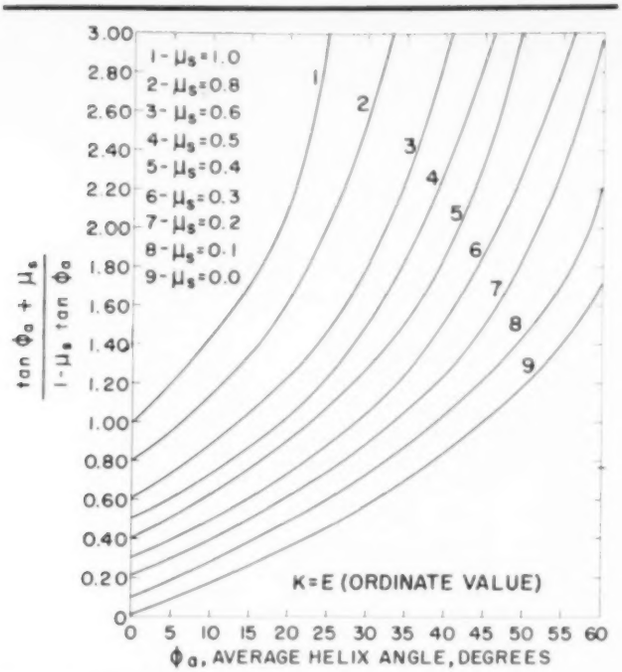


Figure 7. Function vs. helix angle.

Appendix V

Calculation of Expected Output

Values Used in Calculations

Bulk Density	"Zytel" 101 nylon resin	0.475 gm./cc.
	"Alathon" 101 polyethylene	0.490 gm./cc.
	"Lucite" 140 acrylic resin	0.613 gm./cc.
Coefficient of Friction		
	"Zytel" 101 nylon resin	0.25
	"Alathon" 10 polyethylene	0.40
	"Lucite" 140 acrylic resin	0.50

Example of Calculation of Feeding Capacity of Screw A for "Zytel" 101 Nylon Resin

Screw Dimensions: t = 2.00"
D = 1.991"
D − 2h = 1.375"
e = 0.200"
h = 0.313"

$E = (D - h)/D = 0.843$

$C = (D - 2h)/D = 0.69$

$\tan \phi(\text{sub a}) = t/\pi(D - h) = 0.379$

$\phi(\text{sub a}) = 20.7$

$\tan \phi(\text{sub s}) = t/\pi(D - 2h) = 0.464$

$\phi(\text{sub s}) = 24.9$

$\cos \phi(\text{sub s}) = 0.907$

$\sin \phi(\text{sub s}) = 0.421$

$\tan \phi(\text{sub b}) = t/\pi D = 0.32$

From Figure 7, for $\mu(\text{sub s}) = 0.25$ and $\phi(\text{sub a}) = 20.7°$

$$\frac{\tan \phi_a + \mu_s}{1 - \mu_s \tan \phi_a} = 0.70$$

$K = E\,(0.70) = 0.843)\,(0.70) = 0.59$

Neglecting the width of the flight and the effects of back pressure and contact with the trailing edge of the flight, Equation 43 and Figure 4 were used to find θ.

$$M = C(K \sin \phi_s + C \cos \phi_s$$

$M = 0.602$ and $\theta = 28°$

$$\frac{\tan \Theta \tan \phi_B}{\tan \Theta + \tan \phi_B} = 0.200$$

By Equation 13

$$\frac{Q}{N} = \frac{\pi^2 Dh(D-h) \tan \Theta \tan \phi}{\tan \Theta + \tan \phi} = 2.04 \text{ in}^3/\text{rev.} = 33.8 \text{ cc./rev.}$$

Taking into account the volume occupied by the flight by multiplying the output by (t-e)/t: (33.8 cc./rev.)
[(2.00" − 0.20")/2.00"] = 30.4 cc./rev.
(30.4 cc./rev.) (0.475 gm./cc.) = 14.4 gm./rev.

Similarly:

Computed Outputs in gm./rev.

	Screw A	Screw B	Screw C
"Zytel" 101 nylon resin	14.4	26.5	25.4
"Alathon" 10 polyethylene	13.0	23.2	23.2
"Lucite" 140 acrylic resin	15.3	25.3	26.3

Nomenclature

a, b, c = symbols for sides of triangle
C = (D − 2h)/D
D = diameter of screw
e = land width of flight
E = (D − h)/D
df(sub B) = force exerted from barrel surface on plug in length dx
dF(sub f) = force exerted on plug from flight surfaces of channel in length dx
dF(sub n) = normal force exerted from trailing edge of flight to solids plug in length dx
dF(sub s) = force exerted on plug from surface of root of screw in length dx
h = depth of channel
K = ratio of forces acting perpendicular to the reference plane to those acting parallel
l = length of helical channel = L sin φ
L = axial length of screw
M = collection of terms in Equation 40
n = number of screw flights in parallel
N = rotational speed of screw (revolutions per unit time)
P = pressure at any distance x
Q = volumetric rate of discharge of screw
t = lead of screw
U = peripheral velocity of screw = πDN
V(sub x) = velocity of plug in direction of screw axis
w = width of screw channel perpendicular to the screw channel = [(t/n) − e] cos φ
x = variable distance measured along helix of channel
δ = clearance (radial) between the top of the flights and the barrel
θ = angle of direction of solids movement, measured from a reference plane perpendicular to the screw axis
μ = coefficient of friction between solids and metal of extruder or screw
φ = helix angle of screw, measured from a reference plane perpendicular to the screw axis
t = time
sub B = at barrel surface
sub a = at average depth of channel
sub s = at surface of root of screw channel
(φ and D written without a subscript are understood to be φ(sub B) and D(sub B).)

The Effect of Heat Treatment On · · ·

The Polishability of Mold Steels

E. E. Lull

Crucible Steel Co. of America

THE USE OF CARBURIZED molds has wide application in the plastic mold industry. Virtually all steels for cold hobbed molds are of the carburizing type. These are used because of their low hardness in the annealed condition. By reducing the carbon content to about .10% maximum, the steel manufacturers are able to anneal various alloy combinations soft enough for practical cold hobbing. Steels with a carbon content at this low level do not develop the necessary physical properties for a plastic mold unless they are carburized to the necessary depth prior to heat treatment.

The majority of cut molds for thermosetting materials are also carburized. A low or medium alloy tool steel with approximately .30% carbon is popularly used. Steels of this composition develop the required toughness to withstand the impact or compressive forces of the process, but do not possess adequate abrasion resistance for long run molding of most thermosetting resins. This is particularly true of the phenolics. A carburized mold develops the desired combination of toughness and wear resistance for these applications.

Carburized molds have also found a place in the field of injection molding. Most mold builders and polishers agree that high hardnesses are necessary to achieve good finishes and high luster. When the ultimate in finish or luster is required of an injection mold, a carburized surface is usually specified.

The foregoing observations indicate that carburizing steels are variously employed by plastic molders because of their physical properties of machinability, toughness, abrasion resistance, and high attainable surface hardness. In addition to these qualities, a good plastic mold steel must also possess an inherent ability to be polished. This requires freedom from pits, slits, flake and other discontinuities. Tool steel manufacturers have made substantial progress toward minimizing these conditions. Improved polishing abrasives and techniques are also being utilized to achieve better finishes. In spite of these advances, occasional complaints of orange peel, shadows, and voids persist. This suggests that another variable, heat treatment, may be contributing to these conditions.

Carburizing and Polishability

It is recognized that many compositions of plastic mold steels are heat treated. The remarks set forth in this paper will be confined to carburizing and its effect on polishability. The observations should not be interpreted as being pertinent to other types of steels or methods of hardening.

To explore the possibility that heat treatment might influence polishability, we attempted to reproduce common variations in the carburizing and quenching cycle. For our investigation, we selected a popular plastic mold

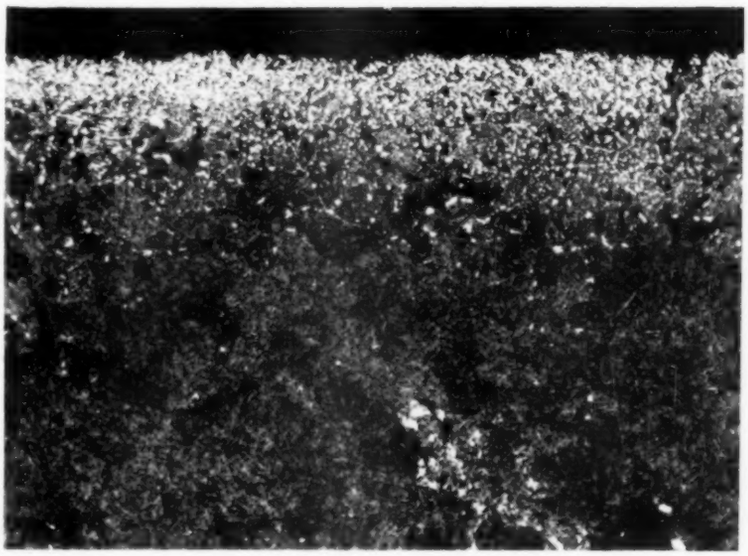


Figure 1

Magnification: X100 Etchant: 2% Nital

Illustrates the uniformity shown by the carburized cases on the specimens that were carburized at 1600F. This particular piece was oil quenched from 1500F.

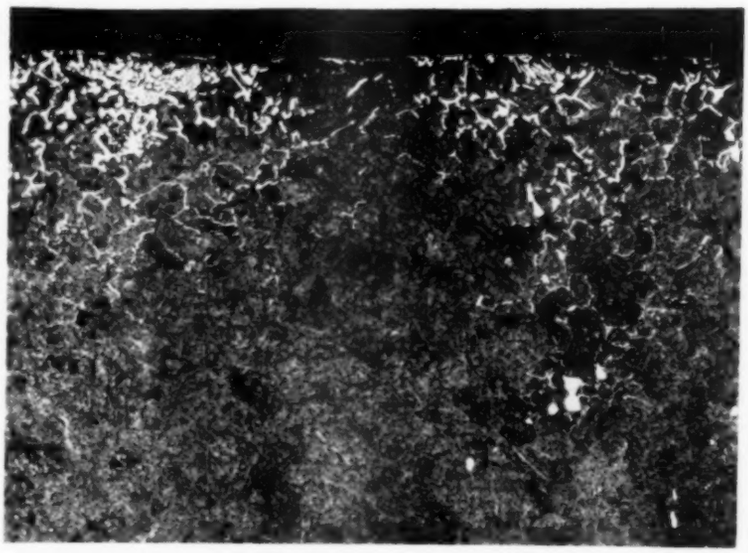


Figure 2

Magnification: X100 Etchant: 2% Nital

Illustrates the scattered, uneven distribution of carbides shown by the carburized cases on the specimens that were carburized at the higher temperatures, especially 1700F and 1750F. This particular piece was oil quenched directly from 1700F.

steel to the following mean chemistry:

Carbon	.30%
Manganese	.75%
Silicon	.50%
Chromium	.80%
Molybdenum	.25%

A sample specimen 1" thick was cut from the center of a 40" x 48" x 28" block. A center section was chosen as being representative of the surface most likely to be polished on a finished mold. The 1" thick section was re-cut into 12 pieces 1" square x 6" long and identified. These pieces were then divided into four equal groups and carburized at temperatures ranging from 1600°F to 1750°F with 50° increments. The specimens were packed in 100% Woodside Rapid Carburizing Compound #2 and held at their respective temperatures for the necessary time to achieve a uniform case depth of .070".

Several check pieces were included in each group of three specimens to determine when the desired depth was reached. The time at temperature necessary to achieve the depth is shown in Table I.

Table I—Carburizing Time

Carburizing Temperature	Time Required at Temperature to Obtain a Case .070" deep
1600°F	28 Hours
1650°F	22 Hours
1700°F	19 Hours
1750°F	16 Hours

A case depth of .070" was selected as representative of the case usually specified for very large molds. This depth permits sections weighing several tons to be machined for fitting after heat treatment without danger of removing the case. This degree of precaution is not necessary for smaller sections and the time at temperature shown in Table I could be substantially reduced.

After each group had been carburized to the desired depth, one specimen was oil quenched directly from the pack, another removed and quenched from 1550°F and the third removed and quenched from 1500°F. All pieces were tempered for two hours to a case hardness of 56-57 Rockwell C as shown in Table II. The pieces were also re-tempered at 500°F for two hours to avoid as much untempered martensite in the case as possible.

Table II—Tempering Temperatures

Code	Carburizing Temperature	Quench	Tempering Temperature Resulting in a Case Hardness of Rockwell C 56-57
1A	1600°F	oil-direct	650°F
1B	1600°F	1550°F-oil	650°F
1C	1600°F	1500°F-oil	650°F
2A	1650°F	oil-direct	650°F
2B	1650°F	1550°F-oil	650°F
2C	1650°F	1500°F-oil	650°F
3A	1700°F	oil-direct	650°F
3B	1700°F	1550°F-oil	650°F
3C	1700°F	1500°F-oil	650°F
4A	1750°F	oil-direct	675°F
4B	1750°F	1550°F-oil	675°F
4C	1750°F	1500°F-oil	675°F

After the second temper each specimen was cut into four equal parts and coded as in Table II. The 48 coded pieces were sent to four independent mold makers for polishing and evaluation. They all received one piece representing each of the heat treatments outlined in Table II.

The polishability evaluation was not consistent in all instances, but there was an area of agreement as to the best and poorest. Three polishers designated 1C as the best while the fourth selected 1B. All agreed that Group 2 did not polish as well as Group I but found it difficult to differentiate between A, B, & C. In groups 3 and 4, it was also difficult to differentiate between the quality of the individual pieces but there was unanimous agreement that Groups 3 and 4 represented the poorest polishability.

According to these evaluations, all specimens carburized at 1600°F rated good polishability and those quenched from 1500°F within the group were considered best. All specimens carburized at either 1700°F or 1750°F were rated very low. It is significant to note that a marked degree of polishability was discernible within a carburizing temperature gradient of only 100°. This would indicate that as the carburizing temperatures increase, the polishability decreases.

Figure 1 is a cross sectional photomicrograph of a 1C specimen. The photomicrograph was made from an unpolished surface adjacent to that actually polished for evaluation. In this manner, we can examine a surface reasonably identical to that which was presented to the polisher. An examination of this and all other specimens within Group 1 revealed that the primary cases possessed a uniform distribution of fine carbides to a depth of .008" to .010". There were no large carbide free areas nor indications of network. None of the specimens in this group revealed the presence of retained austenite in the matrices. A uniform hardness of 56-57 Rockwell C across the surface was recorded. Because of the fine and evenly distributed carbides in the primary case we could expect molds possessing these characteristics to be polished to a fine finish and high luster with freedom from pull out.

Figure 2 is a cross sectional photomicrograph of a 3A specimen. The procedure by which it was obtained is similar to that outlined for Figure I above. An examination of the primary cases of groups carburized at the higher temperatures, especially Groups 3 and 4, displayed an uneven distribution of large carbides. It also reveals some carbide network between the grain boundries. There was also some evidence of retained austenite in the matrices of Groups 3 and 4. It should be interesting to note at this point that the retained austenite was observed in only trace quantities. It was not as pronounced as might be expected from carburizing at temperatures even as high as 1750°F. This soft constituent had an imperceptible effect upon the polishability of the specimens investigated.

Micro hardness tests disclosed the scattered carbide rich areas shown in Figure 2 were as much as 8 points higher in Rockwell C than the areas showing no carbides. This fluctuation in hardness could cause a variation in the amount of metal removed by each polishing stroke. This would result in a series of crests and depressions commonly described by polishers as orange peel.

After removing a few thousandths of an inch of surface metal from the face of a mold similar to Figure 2, we can visualize a situation where polishing would occur on a relatively large carbide rich area at 56-57 Rockwell C and simultaneously on an equally large carbide-free area only 48-49 Rockwell C. Because finish or degree of luster is influenced by the hardness of material being cut we can anticipate a differential in luster between the carbide rich areas and adjacent carbide free areas. In instances where these areas are large, the differential in luster would produce an optical condition known by plastic molders as "shadow."

Figure 2 also displays some network of carbide be-

(Please turn to page 39)

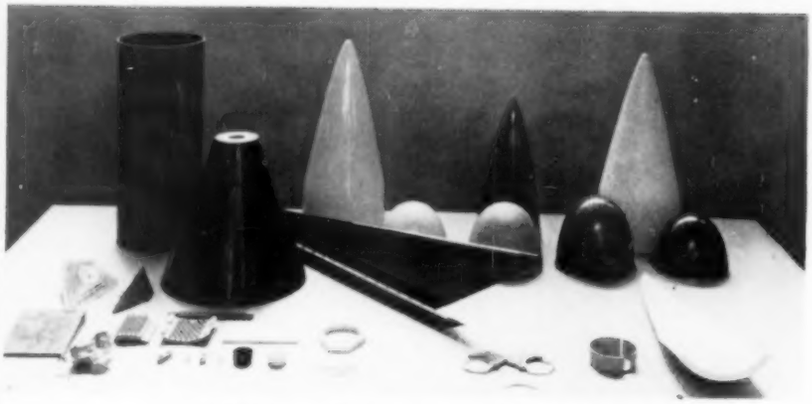


Figure 1. These are typical guided missile components which are molded of plastics.

Compression

L. B. Keller and W. R. McGlone
Hughes Aircraft Co.

PLASTICS HAVE ACHIEVED a prominent position in the production of guided missiles. Their high strength-to-weight ratio, excellent electrical properties and ability to be fabricated into complex shapes make them highly suitable for use in the manufacture of many missile parts.

In early missile designs, plastics parts were machined from rod and sheet stock or were laminated at low pressures on temporary tooling. As missile requirements became better known and as design of some components became more standardized, compression and transfer molding techniques substantially replaced early fabrication methods. The techniques used have evolved from the fabrication of polyester fiber-glass layups on plaster tooling to the present use of high-pressure molding in matched metal dies for large-scale production of high-quality parts. At the present time, experimental molds and molding processes are developed suitable for use in full-scale production in any qualified production facility.

The adaptation of established molding methods to the development and manufacture of missile components was not accomplished without difficulty, because the unique and rigorous requirements applying to missile parts necessitated refinements in molding techniques. This paper outlines the techniques of compression and transfer molding currently used by the authors along with discussions of some of the problems concerned with development of the processes and techniques and the manner of their solution. Comparisons will be made to the techniques commonly used in the plastics industry.

Missile Part Requirements

A guided missile is essentially a pilotless aircraft carrying a complex electronic system, a power supply, a propulsion unit, and a warhead. To accomplish its purpose it must travel at a very high speed and the electronic system must function perfectly, providing information used to adjust the course with great rapidity. The missile must be able to operate under extremes of ambient temperature and after long periods of storage. The foremost requirement for all guided missile parts is, therefore, a high degree of reliability, surpassing that considered necessary in most other plastics parts. In some missile designs, very limited space is available; this imposes the additional requirement of miniaturization.

Plastics missile parts may be divided into two general classes, structural or electrical, according to their primary function. All missile parts, however, must resist high acceleration loads, conform to high standards of dimensional accuracy and stability, and have the least possible weight.

Structural plastics missile components are usually mounted externally on the missile. Their strength properties at operating temperatures must compete with those of the lighter metals, and they must have a sufficiently high modulus of elasticity to withstand the deflection and flutter of supersonic flight. They should withstand the erosive effects of air and rain at supersonic speeds and must retain strength and dimensional integrity under rapid aerodynamic heating to temperatures as high as 500°F. In addition to clean, smooth aerodynamic surfaces some structural parts must also have good electrical properties during flight. Radomes are unique in that they must satisfy severe structural and electrical requirements.

Most electrical missile plastics parts are mounted inside the missile. Because of the space and weight limitations imposed by the missile system, the parts are often small, precise, and of such an unusual shape that they are difficult to mold. These parts, generally designed to function at ambient temperatures of −65°F to 180°F, must resist abrupt changes in temperature, humidity, and atmospheric pressure, and must also retain suitable properties and dimensional stability under both operational and storage conditions.

Special materials and new processes are often used in the development of plastics parts that will meet these difficult requirements. It has been found that high quality must be the guiding principle in part development in order to achieve the reliability desired. Only those parts that have been thoroughly engineered through all phases of development, including part design, material selection and evaluation, tool design, tool fabrication, process development, and final product testing can be expected to attain the required degree of quality and reliability.

Typical Parts

Plastics missile parts range from electrical parts the size of a match head to reinforced laminated structures several feet long. Most of the small and intricate electrical parts are transfer molded; simple shapes or parts having both electrical and structural requirements are usually compression molded. Large, highly-stressed parts are made of reinforced laminates by compression molding at high pressures in matched metal dies. An

and Transfer Molding of Guided Missile Parts

example of each of the above types is given below.

Shown in Figure 2 is a typical transfer-molded part designed to serve as the holder for a wiring and contact assembly. Because of the shape and close tolerance dimensions required for this part, it is fabricated in a carefully engineered transfer mold under precisely controlled conditions. The part functions primarily as an insulator and contact holder; therefore, it has to maintain high d-c resistivity and dimensional stability under severe humidity and temperature conditions. Since this part is exposed to a momentary rocket blast and must be reusable several times without replacement, it was necessary that the material selected have a very short flame-out time in case of ignition. These requirements were all met by a special polyester-fiber-filled diallyl phthalate molding material.

The contact plate shown in Figure 3 is an example of a compression-molded part. Although primarily electrical in function, it is required to withstand a flexural load of about 300 pounds, and the convex face of the part must withstand exposure to the air stream in flight. The tolerance on the locating dimension of each of the large number of inserts is ±0.0025 inch. The insulation resistance required between any two contacts after several days exposure to severe humidity cycling is 100 megohms minimum.

Many precautions were taken in the manufacture of this part to insure dimensional, electrical, and structural integrity. Compression-molding techniques combined with the use of shaped preforms provided consistently high strength-values. The inserts were designed to pierce the preforms as the mold closed, thereby minimizing flow patterns and improper fiber orientation (see Figure 4). Preforms were made from dried material and stored in desiccators. Just prior to molding, each preform was preheated either electronically or in an oven and then molded with a cure time of 12 minutes. Despite all these precautions, the glass-fiber-filled material first selected occasionally failed under humidity test. The material now used, which satisfies all requirements, is a diallyl phthalate, orlon-fiber-filled molding compound.

Most laminated plastics structures are fabricated by compression-molding techniques with hardened steel tooling similar in many respects to conventional compression molds. The main difference between the compression molding of bulk materials and that of laminates is that in the molding of laminates little or no change occurs in

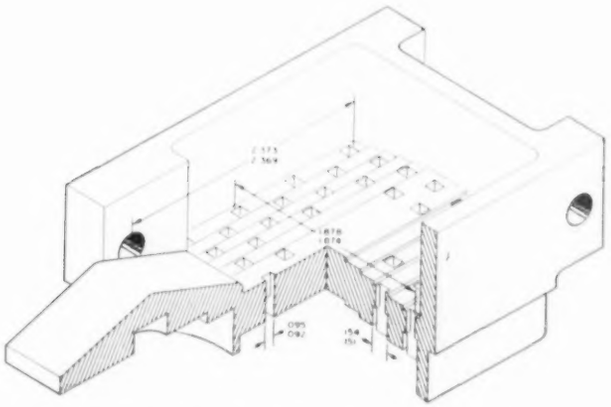


Figure 2. Typical transfer-molded part showing several close tolerance dimensions.

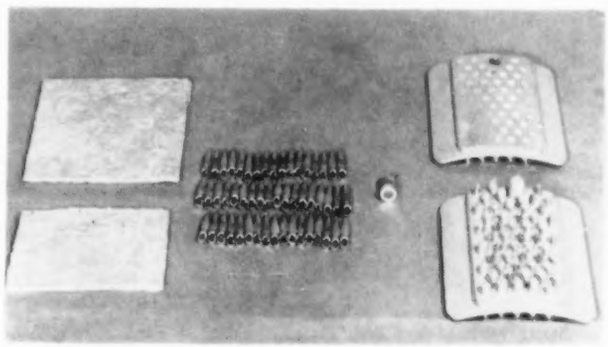


Figure 3. Typical compression-molded part, showing preform, inserts, molding and finished machined part.

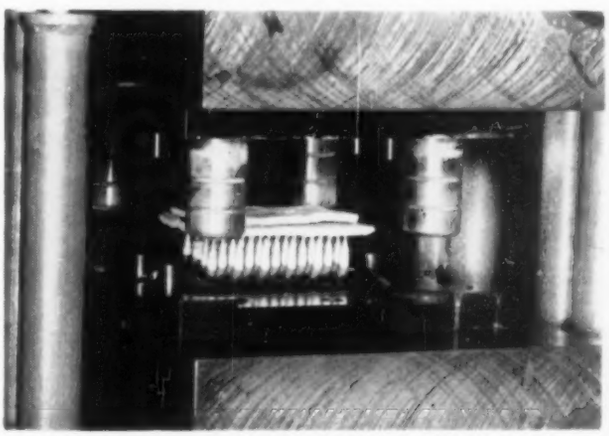


Figure 4. Preform resting on pointed inserts in open mold.

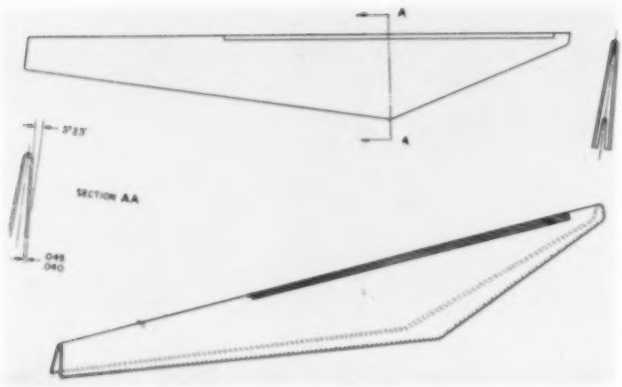


Figure 5. Stabilizer glove—typical compression-molded laminate.

the position of the reinforcing material, whereas in the molding of bulk materials both the resin and filler flow in the mold.

The stabilizer glove shown in Figure 5 is a typical compression-molded laminate. It must consistently exhibit high flexural strength and rigidity, even though it is subjected to severe aerodynamic loading and heating (to 500°F). As an airfoil surface it must be smooth and resist erosion by air and rain at elevated temperatures. Its over-all dimensions, including thickness, are governed by close tolerances. The part must have fairly low moisture absorption properties in order to prevent blistering and delamination caused by rapid temperature rises during flight. Some stabilizer gloves must also act as electrical insulators. This combination of high strength, high modulus of elasticity, temperature resistance, dimensional accuracy, and fairly low moisture absorption was extremely difficult to achieve. The stabilizer glove is currently made from a carefully tailored layup of glass cloth, pre-impregnated with high-temperature-resistant phenolic resin, molded in a matched steel tool at pressures of 9,000 to 12,000 psi (based on projected area).

Materials

With the exception of materials containing cellulose fillers (which are inadequate because of susceptibility to fungus attack) practically all types of high-grade thermosetting molding materials have been used in the fabrication of missile plastics parts. Although mineral-filled molding compounds of melamine, phenolic, and alkyd appear satisfactory for electrical applications, they are somewhat weak and brittle. The best combination of outstanding electrical properties and good mechanical strength has been achieved in parts molded from orlon-fiber-filled diallyl phthalate molding powder. Table I compares the properties of this material to those of other molding compounds. The combination of suitable physical properties and high d-c resistivity after humidity cycling suggests that this material be used in fabricating connectors, terminal boards, switch rotors, slip rings, and other electrical parts.

Another unique property important in electrical applications is the ability of the molded part to withstand the temperatures caused by soldering. Orlon-filled diallyl phthalate does not crack, as do many mineral-filled materials, when soldering operations are performed on molded-in inserts. Its retention of electrical properties after soldering is also outstanding.

For applications requiring high mechanical strength, compounds are available that contain glass fibers as filler. Glass fibers may be combined with resins such as phenolics, silicones, alkyds, and polyesters to produce molding materials having the strength properties shown in Table II. Weak areas resulting from resin segregation in parts molded from these materials can be avoided by eliminating thin walls and barriers to flow in the mold. Preforming often helps to place the fibers properly and to distribute them more uniformly throughout the part.

The choice of materials for reinforced structural missile parts has been rather limited. The requirements for high strength and rigidity at temperatures as high as 500°F eliminate practically all of the commonly used materials. Only certain heat-resistant phenolic resins properly combined with the highest strength glass-cloth

TABLE I

Electrical Properties of Various Molding Materials

Material	Insulation Resistance As Molded	Insulation Resistance Immediately After Humidity Cycling **	Insulation Resistance 24 Hrs. After Humidity Cycling	Insulation Resistance After Soldering ***	Ultimate Flexural Strength Psi ASTM-D-790	Impact Strength Izod Foot-Lbs. Per Inch Notch	Specific Gravity
	Megohms	Megohms	Megohms	Megohms			
Orlon Fiber Filled Diallyl Phthalate	1,000,000	800,000	1,000,000	900,000	11,700	1.0*	1.24*
Electrical Grade Mineral Filled Phenolic	900,000	45,000	200,000	3,350 47% Cracked	7,900	0.28*	1.74*
General Purpose Wood Flour Filled Phenolic	19,000	34	119	———	9,000*	0.28*	1.35*

*Data from manufacturers' literature

**Insulation resistance between molded-in terminals separated by 0.100" of plastic material. Humidity cycle according to Mil-E-5272 paragraphy 4.4.- procedure 1.

***Soldering tests — terminals soldered with 100-watt iron for 10 seconds.

reinforcements have been found satisfactory. Yet, even these materials fail unless the strictest control is maintained during material manufacture and throughout the fabrication process. Selection of the material for structural parts is generally made only after extensive process development and testing of flat panels. Representative curves showing the flexural strength versus temperature of various laminates as panels are given in Figure 6.

After a material meeting the above requirements has been found, further work is necessary to adapt the processing techniques to shaped parts. Physical values for high-pressure heat-resistant phenolics like the values shown in Figure 6 are not consistently obtained in shaped parts, but values of 35,000 psi flexural strength and 2.5 x 10^6 psi flexural modulus at 500°F can be maintained. These processes will be discussed further in the section titled "The Molding Process." All of the compounds mentioned above are commercially available in this country.

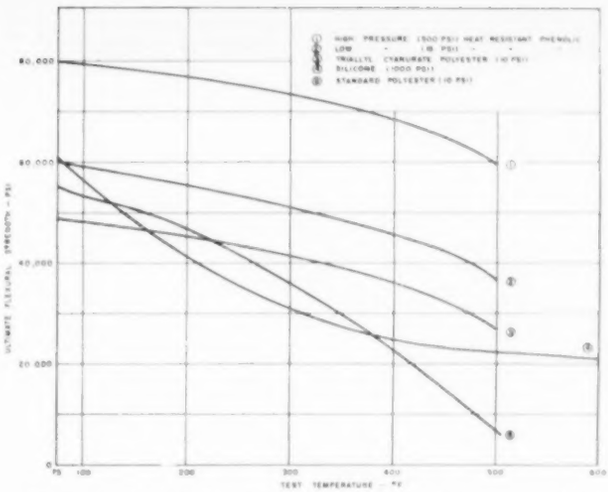


Figure 6. Flexural Strength plotted against temperature for several laminates.

Molds

In the compression and transfer molding of thermosetting materials, attention to the details of mold design and the selection of suitable mold materials are important in obtaining high-quality parts. Although a part made in a poorly designed mold can appear adequate, it may be inferior in electrical and physical characteristics, and may not consistently meet dimensional requirements.

Parts machined from solid blocks of molded material seldom have the same characteristics as the corresponding moldings of the same shape. Also, temporary, mock-up, or shop-practice tools rarely produce parts equal in quality to those made in a carefully engineered production-type mold. Low reject factors and long-range economies can be achieved by the use of sufficient care in the design and fabrication of a mold. Our experimental tooling usually has the quality of production tooling; it is characterized by the following features: high-rigidity, self-contained semi-automatic operation, provision for precise control of molding conditions, and integral heating systems.

Special attention to mold rigidity helps to ensure the dimensional accuracy of the moldings. Since the molded shapes are often complex and the mold cavity may be pierced by many pins, it is essential that adequate support be provided in order to prevent undue deformation of the mold under pressure. Heavy mold plates are used and unsupported areas are kept to a minimum. When wide ejector plates are necessary, supporting pillars are provided. A stress analysis is made if there is any doubt of the ability of a proposed construction to withstand the loads. Stress analyses are particularly important in the construction of compression molds for laminates (Fig. 7). Extreme lateral thrusts may occur in the punch and cavity due to the uneven loading of the mold by a wrinkled preform or because of too highly advanced material.

Another reason for emphasizing rigidity in mold construction is that the position of inserts, cores, and pins operated by the ejection system often defines precise dimensions in the part. The mold base must be accurately and rigidly constructed because it acts as a cradle and guide for the ejector system. In order to re-

TABLE II

Physical Properties of Glass-Filled Molding Compounds

	Flexural Strength Psi*		Flexural Modulus Psi*		Impact Strength Izod.	Tensile Strength	Specific Gravity
	Room Temp.	500°F	Room Temp.	500°F	Ft. Lb./inch Notch	Psi	
Glass Fiber-Filled Alkyd	21,500	——	2.3 x 10^6	——	8-12	6,000-10,000	2.04
Glass Fiber-Filled Polyester	28,000	——	1.9 x 10^6	——	12-24	———	1.8
Glass Fiber-Filled Silicone	10,000	4,300	1.6 x 10^6	.80 x 10^6	15	4,400	1.65
Glass Fiber-Filled Phenolic	25,000	20,000	2.9 x 10^6	1.9 x 10^6	8-15	12,000	1.9
Glass Fiber-Filled Triallyl Cyanurate Polyester	21,000	7,300	1.75 x 10^6	.79 x 10^6	12-24	———	1.8
Glass Fiber-Filled Diallyl Phthalate	9,000	800	1.25 x 10^6	——	12	4,700	1.6

*Flexural tests made at HAC on ⅛" x 1" x 4" bar using ASTM method D-790. All other values are from manufacturers' literature.

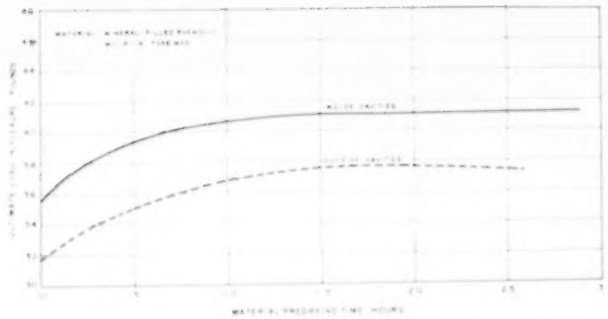


Figure 7. Flexural strength versus pre-day time for various cavities of terminal board mold.

sist bending, ejector bars are built unusually thick and are designed to have as short a span as possible.

Stripping loads are sometimes high and often comparable to the molding loads. In one mold the ejector system must operate almost 60 pins in both the upper and lower mold sections. The lower pins hold the inserts and eject the part; the upper pins clamp the inserts and clean out flash in the upper holes. The ejector plate was built sufficiently thick to resist bending under the high stripping load, because minor deflections would cause galling and binding of the ejector pins. The plate is "H"-shaped and has four actuator rods to provide even operation without tilting.

The effect of rigidity in mold construction is illustrated by the following example. Terminal boards made from a standard mineral-filled material were failing in operation due to low insulation resistance. The four-cavity semi-positive compression mold used in making these boards was investigated to determine whether the material or some other factor was the reason for failure. A direct correlation was found between the averages of insulation resistance and flexural breaking loads over a wide range of molding conditions, although a fairly large spread existed in the data for any given set of conditions. The average of the flexural strength characteristics of parts from the two outside cavities and the average of these characteristics for parts from the two inside cavities were plotted against predry time; these curves are shown in Figure 7. Examination of the mold revealed that the two inside cavities were well supported but that the outside cavities were deflecting in a manner that prevented the application of effective pressure on the molding material. It was found that adequate parts could be molded if the material was predried and if a rather long cure time was used.

Semi-automatic molds rather than hand-operated molds are used because of their superior temperature control and because they eliminate the probability of damage to the molds and moldings that is often caused by hand ejection. Ejector systems are integral with the mold construction. The opening motion of the press ejects the parts; no outside operating mechanism is required. Molds of this design will fit and operate in any press having sufficient daylight and stroke. Once the mold is clamped in place, it is ready to operate; this minimizes mold handling and installation time. As stated before, critical dimensions may depend upon the accurate positioning of the ejector bar; a press-operated ejector system introduces errors by requiring additional parts and adjustments. Another advantage of an integral ejection system is its greater rigidity due to the reduced span length of the ejector bars. Initial return of ejection systems may be caused by a pushback incorporated into the ejector operating rod, but the final location is always determined by pushback pins operated from the landing surface of the mold.

Figure 8. Open rotor switch mold and emerging part.

All molds have built-in standard thermocouple wells at strategic points within the mold. These fittings may be attached to intermittent or continuous recording pyrometers so that accurate temperature measurements are available. When precise control of temperature is necessary, the built-in thermocouples act as sensing units in automatic mold temperature-control systems. To reduce variations in temperature due to heat loss, some molds are also thermally insulated.

Another important aid used in maintaining accurate mold-temperature control is an integral heating system. During mold design, a study is made of the steam-core layout to prevent hot or cold spots from developing in the mold. A large heat-transfer area is obtained by the use of many steam cores. A variation of $\pm 5^{\circ}$F or less is maintained on most molds.

In the compression molding of laminates it is often necessary to halt temporarily the closing motion of the mold at an exact distance (a few thousandths of an inch) from complete closing to lands, in order to permit the release of volatiles and to advance the resin to the desired condition of flow. A dial indicator is mounted on the press to measure the distance from closure. If an automatic cycling press is used, the indicator is helpful in setting and maintaining this pre-squeeze or "kiss" distance.

The inflexible and complex design requirements of many small missile parts present a challenge to the mold designer; the mold illustrated in Figure 8 required nine radially operated cores. These cores were all cam operated; the final core location was determined by a second positive cam in order to meet the required close tolerances. Great precision is also necessary in the construction of molds for laminates.

In laminates molded from fiberglass cloth, the amount of filler at any given point is a function of the layup. The resin-to-glass ratio in the final part depends on the amount of resin eliminated during molding. If the mold fails to close to the correct distance, insufficient resin will be eliminated by flow and the part will be resin rich. If the distance between cavity and punch is too small, the laminate will be resin starved. In either case the part may be low in strength and flexural modulus. The graph of resin content versus flexural strength, Figure 9, shows that resin content can be a very critical factor.

In other respects, we follow commonly used principles of mold design. The cross-sections of transfer sprues and gates are made large for molding fiber-filled materials in order to prevent breakage or segregation of the fibers. Most compression molds are of the semi-positive type in order to obtain effective pressure on the material without the need for an exact weighing of the charge. Special attention is paid to land areas because,

if they are too large, excessive flashing may occur unless extremely high clamping loads are used. On the other hand, lands that are too narrow tend to chip and otherwise fail from high bearing pressures. Cavities are usually built of commercially available high-grade tool steel. They are heat treated to give a tough inner core and a very hard outer surface. In the design of all molds, standard retainer plates, mold plates, pins, and ejector bars are used wherever possible.

The Molding Process

The material properties given in manufacturers' literature represent values that are easily obtainable in standard test-specimen molds with routine molding techniques. Optimum molding conditions and specially designed test molds will often produce an apparent upgrading of the materials. In production parts of complex shape it is difficult even to equal the manufacturer's test specimen values, so that the part may fail to meet the designer's expectations unless the optimum molding process is used. Since parts are usually designed from standard test-specimen data, it is imperative, in critical applications, to seek the optimum molding process for a part.

In the development of missile plastics parts, the molding conditions that produce the most desirable properties in a molding are developed by the use of planned molding programs. A series of parts is made under carefully controlled conditions and by varying molding parameters such as temperature, cure time, and pressure. Test programs are statistically planned in order that data may be obtained from the optimum number of specimens of each type. Critical tests on the moldings reveal the process that will produce the best combination of strength, electrical properties and dimensional accuracy in relation to cost. Depending on the material and on the nature and operating requirements of the part, the controlled molding program may be either limited or very extensive. Experience derived from similar parts is very helpful in determining the scope of the program and the range of parameters. Equivalent production parts can be reproduced if the process developed is one that can be duplicated and if the material is consistent from batch to batch.

In many small parts the proper choice of material and reasonable care in molding are sufficient to maintain adequate physical and electrical properties; however, to attain high dimensional accuracy and uniformity, precise process control is essential. The material shrinkage factor applied in any cavity design is at best an enlightened guess based on previous experience and the most probable molding conditions. The actual dimensions of the molding will depend upon many factors, such as the shape of the part, molding pressure, cure time, cure temperature, and material pretreatment. High shrinkage and large shrinkage-variation caused by process conditions are characteristic of those synthetic fiber-filled materials that are particularly suited to electrical applications.

Figure 10 shows the effect of cure time and temperature on the shrinkage of diallyl phthalate orlon-filled molding material. These data were obtained from compression-molded discs $\frac{3}{8}$ inch thick and 5 3/16 inches in diameter. These discs showed a maximum variation of ±0.001 inch in diameter for any given set of conditions. Measurements of more complex shapes have indicated that the trends shown in Figure 10 are typical for this material; however, the actual shrinkage at any condition will vary slightly in magnitude.

Transfer pressure may also have a significant effect on the dimensions of molded parts. The parts produced by the mold shown in Figure 8 was essentially a right cylinder having an outside diameter of 0.750 inch. Variations in transfer pressure produced corresponding variations in the diameter of the part as shown in Figure 11. Even within the usual transfer-pressure range (3000 to 12,000 psi) the variation was sufficient to cause rejection.

Shrinkage of glass-fiber-filled and mineral-filled molding materials is usually less than the shrinkage of materials containing organic fibers. The effect of process conditions on mold shrinkage is, however, important. Table III gives shrinkage data for several materials over a range of molding conditions.

Dimensional variations in parts are frequently attributed to lack of uniformity in the molding material. In one instance, very high dimensional reject rates were attributed to variations in molding material. Figure 12 shows the effect of mold temperature on the over-all length of this particular part. The shaded area of the

TABLE III

Molding Shrinkage of Various Materials

Material	Asbestos-Filled DAP	Glass-Filled DAP	Orlon-Fiber-Filled DAP Medium Flow	Polyester-Fiber-Filled DAP	Mineral-Filled Phenolic	Flock-Filled Phenolic	Glass-Fiber-Filled Alkyd
Range of Molding Shrinkage (From HAC Tests) Inches Per Inch	.0065-.0086	.0032-.0046	.0062-.0090	.0092-.0127	.0030-.0035	.0048-.0065	.0017-.0028
Recommended Molding Shrinkage Factor for Curetime and Temperature indicated (From HAC Tests) Inches Per Inch	.008 FOR 8 MIN. AT 300 F	.0045 FOR 8 MIN. AT 300 F	.008 FOR 8 MIN. AT 300 F	.010 FOR 8 MIN. AT 300 F	.003 FOR 8 MIN. AT 300 F	.0055 FOR 6 MIN. AT 300 F	.0025 FOR 2 MIN. AT 285 F

Note: All data was derived at HAC from compression-Molded discs (diameter: 5 inches. Thickness: $\frac{3}{8}$ inch)

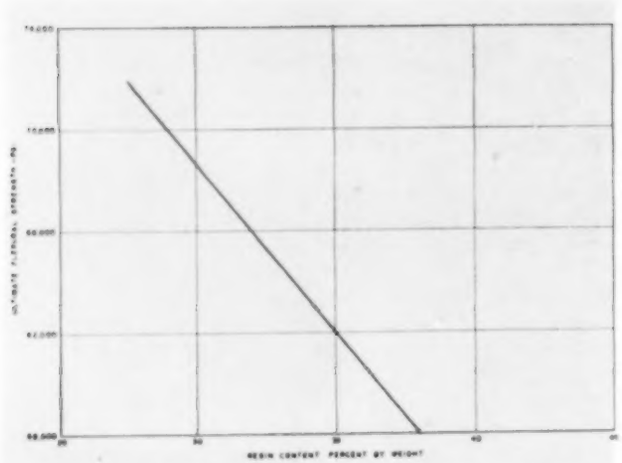


Figure 9. Flexural strength versus resin content of heat-resistant phenolic laminate.

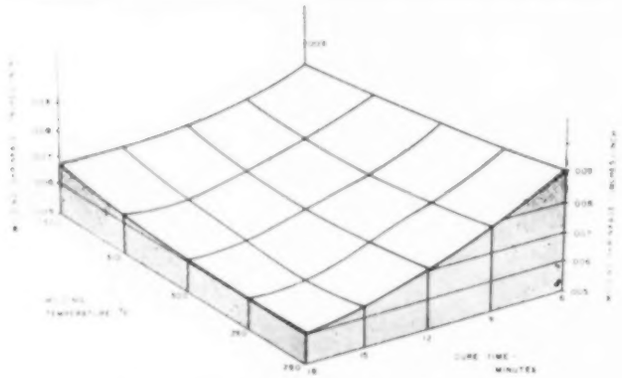


Figure 10. Molding shrinkage versus molding temperature versus cure time of Orlon-fiber-filled diallyl phthalate molding compound.

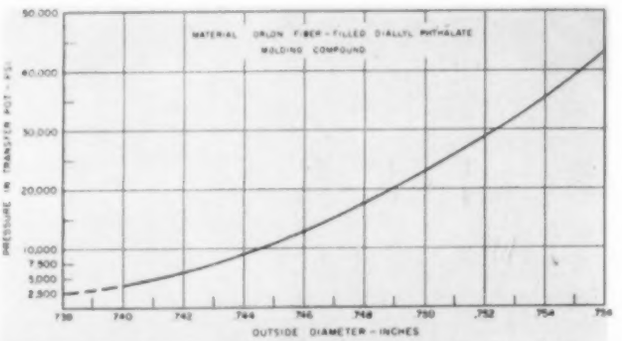


Figure 11. Diameter versus transfer pressure of rotor switch.

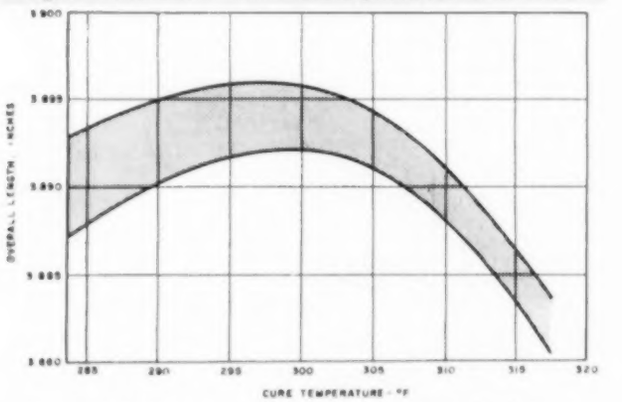


Figure 12. Variation of overall length of contact block versus cure temperature.

graph shows the maximum and minimum sized parts obtained (from as many as 25 parts) at any given molding temperature. Controlled molding and the measurement of the resulting parts proved that the material was remarkably consistent in shrinkage for any given set of molding conditions. Dimensional rejects in this case were directly traced to insufficient process control and faulty mold construction.

Accurate knowledge of the effect of molding conditions on the dimensions of a part not only makes possible the establishment of adequate process control but also is an excellent tool for gauging the uniformity of material from batch to batch. When there are variations in the characteristics of the material, it is usually possible to bring the part within tolerance by adjustment of the molding process.

The electrical characteristics of many molded parts can be improved by a proper choice of processing conditions. After humidity cycling, the d-c resistivity of insufficiently cured parts is likely to be erratic. Predrying at temperatures from 120° to 170°F is often particularly helpful (see Figure 13). The predrying of molding material intended for critical missile electrical parts is standard procedure. The improved insulation resistance of the material is probably due to the removal of volatiles, including moisture, prior to molding and to a stiffening or decrease in flow of the material. Although the use of stiffer material usually results in decreased porosity in a part, the use of such material is, of course, limited in practice by its inability to fill out cavity details.

Strength Characteristics

The strength characteristics of molded parts also vary with process conditions (see Figure 7). Adequate cure is a necessity; undercure, and in some cases overcure, result in loss of strength. Most thermosetting resins combined with mineral or glass fillers are difficult to overcure, but organic fiber-filled compounds may suffer reduced strengths due to elevated cure temperature or excessive cure time. Figure 14 illustrates the effect of molding temperature on the ultimate breaking load of a nylon flock-filled phenolic part. Extended cure time also tended to reduce the strength of this part.

In the compression molding of bulk materials, the resin and filler should flow as a single phase in the mold, and the resin content of the finished molding should be almost identical with that of the uncured molding powder. In laminates, however, it is necessary to eliminate a portion of the resin by flow from the cavity without excessive disturbance of the glass reinforcement. The amount and the duration of flow of resin is a most critical factor in the production of high-strength temperature-resistant structures.

The fabrication of temperature-resistant laminated structures is described as compression molding because high pressures and fixed cavity volumes are used. In addition to the system of variables involved in conventional compression molding, several other factors must be recognized and controlled.

The material used is standard glass cloth impregnated with heat-resistant phenolic resin. During impregnation the resin is advanced to the "B" stage, resulting in a fairly stiff, dry product. The material is controlled by the impregnator for resin content, volatile content, and greenness or degree of advancement. Nevertheless, the material is tested as received in order to insure uniformity. This material is easy to cut and to lay-up flat, but it must be warmed in order to preform it into more com-

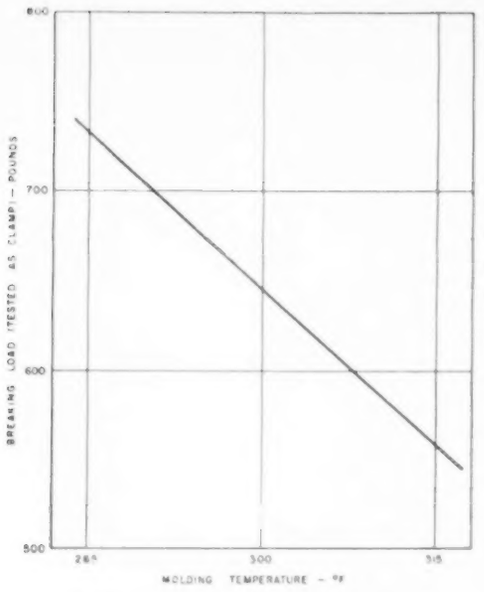


Figure 13. Breaking load versus molding temperature for relay clamp.

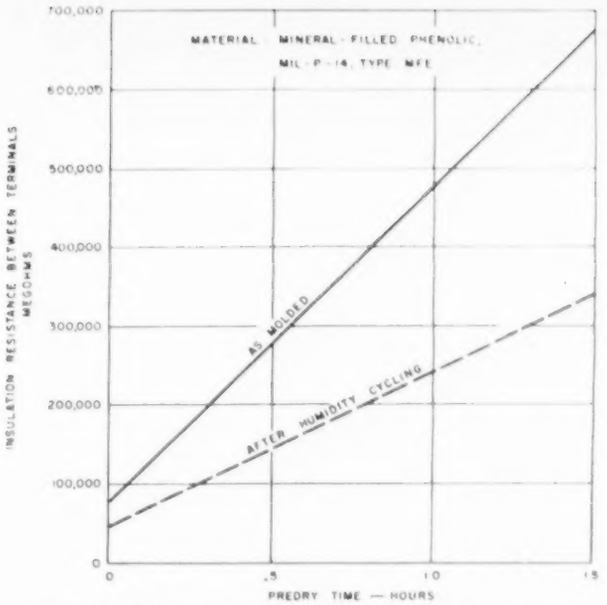


Figure 14. D-C resistivity versus pre-dry time for terminal board.

plex shapes. Layups generally are made oversize and, in molding, the excess layup is cut off in the punch and cavity. This is accomplished by a combination of lands and pinch-offs. All the molds close to fixed lands which, in combination with the pinch-offs, provides a fixed cavity volume.

Before molding, the material is often dried to remove volatiles and advance the resin to the most suitable state for molding. Before the application of pressure, it is often necessary to preheat (or "kiss") the material in the mold. The mold temperature, the "kiss" distance, "kiss" time, and speed of closing from the "kiss" position all affect the qualities of the resulting part. Cure time is less critical since the parts are invariably given a drastic postcure cycle.

To recapitulate, some of the variables that must be controlled in the compression molding of laminated structures are:

a. Resin content of raw material.
b. Volatile content of raw material
c. Greenness of raw material
d. Preforming temperature and time
e. Predrying temperature and time
f. "Kiss" time and distance
g. Speed of closing
h. Mold temperature
i. Cure time
j. Postcuring schedule

Despite its complexity, this technique is well adapted to the production of high-quality laminated structures of fairly simple shape. Cure times are short, comparable to normal compression-molding cycles, porosity is low, due to high pressures; the parts are dimensionally accurate because rigid landed molds are used. Pressures normally vary from 400 to 1000 psi, based on the projected area of the cavity; however, pressures of as high as 20,000 psi are sometimes used.

The success of this high-pressure laminating technique depends almost entirely on process control and on a knowledge of how changes in conditions affect a part. Adequate parts will not be produced unless the proper conditions of resin flow have occurred in the mold and the resin content of the parts is in the correct range (see Figure 9). Very porous parts may result from insufficient or too much "kiss" time, improper resin viscosity, incorrect layup, and many other factors.

Conclusion

By the proper use of the techniques described in this paper, compression and transfer molding have been successfully applied in the fabrication of missile parts meeting extremely rigorous requirements. Some of the methods employed may be extended to other fields as requirements become more severe. Before plastics can completely fulfill their promise as engineering materials, a better understanding of the molding processes must be gained, new and improved materials must be developed, and the application of accurately controlled processing must be more universally adopted.

Polishability of Mold Steels . . .

(Continued from page 31)

tween the grain boundries. The influence of carbide network on polishability has not been fully determined by this work. There are reasons to believe that it would facilitate "pull out" in the form of carbide particles. "Pull out" of this type can be distinquished by a characteristic scratch or tail emanating from the void and is not to be confused with the "pull out" of non-metallics referred to by the steel maker as pits.

It would be erroneous to assume that ununiform distribution of carbides, variations in hardness, and network are the only conditions responsible for orange peel, shadow, or "pull out." It must be concluded that they are strong influencing factors. The degree to which they influence polishability can be eliminated by carburizing steels of the type investigated at 1600°F and quenching from 1500°F to 1550°F.

Calculation of Roll Forces . . .

(Continued from page 19)

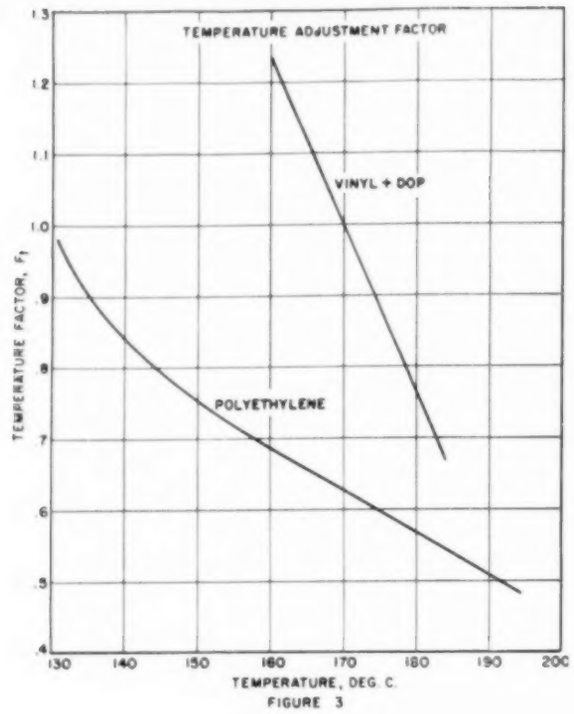


FIGURE 3

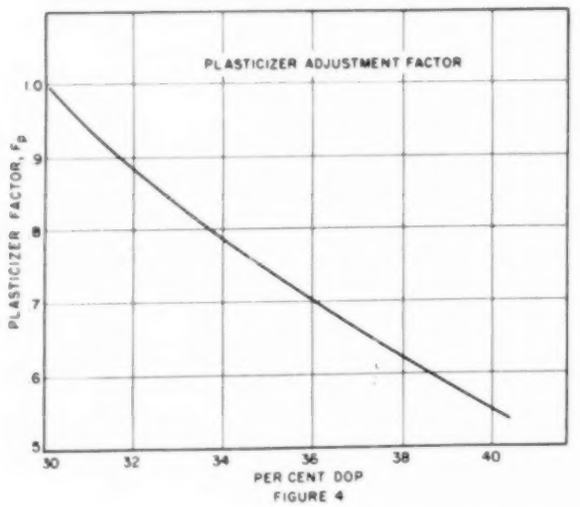


FIGURE 4

material balance between these points must give the result that $h_2 = h_0$. It is assumed in this that the material is neither compressible nor has the ability to recover deformation.

Ardichvili's analysis, furthermore, yields the result that h_1 is 4/3 h_0. Therefore, the assumption that

$$h_2 = h_1 = 4/3\ h_0 \qquad (6)$$

has theoretical basis, and the value for h_2 has been experimentally confirmed for vinyl material.

Using the value of h_1 given by (6) Ardichvili arrived at the following expression for the pressure distribution:

$$P = 4\ \eta\ V\ [(r\ (h - h_0)]^{1/2}/h^2 \qquad (7)$$

where P is the gage pressure, η is the viscosity of the material, and the other symbols have the significance indicated in Figure 5.

It can be shown that

$$x^2 = 2\ r\ (h - h_0)/2 - (h - h_0)^2/4 \qquad (8)$$

Neglecting the last term and solving for x, one has the approximation that

$$x = [(r\ (h - h_0)]^{1/2} \qquad (9)$$

or for h in terms of x,

$$h = (x^2 + r\ h_0)/r \qquad (10)$$

Substituting (10) into (7) and integrating over the limits x = o and x = X, where X is the value of x at h = H, one obtains an expression for the force per unit length of roll. Substituting back into terms of h by (9), Equation (1) is obtained. This is the basis for the method of force calculation, and the results reported here show satisfactory agreement between calculated and measured values.

In order to use Figures 1 and 2 to obtain the apparent viscosity appropriate to the particular rolling process being examined, the apparent shear rate and shear-time number for the rolling process must be known. These are derived from Ardichvili's equations. His expression for the change in pressure with x is

$$dp/dx = 12\ \eta\ V\ (1/h^2 - h_1/h^3) \qquad (11)$$

It may be shown, also, that (1), (3)

$$dp/dx = d\tau/dy \qquad (12)$$

Combining (11) and (12), for any given value of x the result is

$$d\tau = 12\ \eta\ V\ (1/h^2 - h_1/h^3)\ dy \qquad (13)$$

Therefore

$$\tau = 12\ \eta\ V\ y\ (1/h^2 - h_1/h^3) \qquad (14)$$

where the constant of integration has been dropped because τ = o at y = o. Equation (14) will have a maximum value at the roll surface where y = h/2. That is

$$\tau(\text{sub w}) = 6\ \eta\ V\ (1/h - h_1/h^2) \qquad (15)$$

from which the maximum shear rate, S(sub w), with respect to y, is determined. Thus

$$S(\text{sub w}) = \tau(\text{sub w})/\eta = 6\ V\ (1/h - h_1/h^2) \qquad (16)$$

This will have its maximum with respect to the x axis at the nip where h = h_0. Combining this with (6) yields

$$S = -2\ V/h_0 \qquad (17)$$

The scalar magnitude of the maximum shear rate, therefore, is $2V/h_0$. This will correspond to the shear rate at which apparent viscosity is determined by the capillary flow method and may be used to read apparent viscosity from Figure 1.

As has been shown, the apparent viscosity is related to another quantity, namely, the time under shear, τ(sub s). An average value is used which is estimated from the volume rate of transfer of material through the rolls. The velocity of the roll may be taken as an approximation for the average rate of transfer. The distance traversed while under shear is approximated as the distance between h_1 and h_2. With these approximations and Equation (6) it is evident that

(Please turn to page 60)

Opportunity materials—
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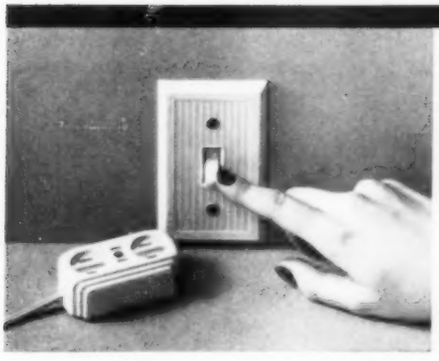

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Action— By Your National Organization

"The objects of the Society shall be to promote in all lawful ways the Arts, Sciences, and Engineering Practices and Standards connected with the utilization of plastics."

At the January 17, 1956 meetings in Cleveland, Ohio, the National Council ratified the amendment of fifteen By-Laws of the Society.

In accordance with Art. XV Sec. 2 C55 of the Society's Constitution these amendments became effective immediately and the By-Laws as amended are here published.

B-15 All fees and dues shall be made payable to the Society of Plastics Engineers, Inc., and shall be collected by the Executive Secretary of the Society.

B-16 The Executive Secretary of the Society shall remit to each Geographical Section, five ($5.00) dollars of the annual dues collected from members affiliated with that Section; except in the case of Junior Members, whereby only three dollars and fifty cents ($3.50) shall be remitted; and shall remit one half of the initiation fees collected; except that during the first twelve months following the organization and recognition by the National Council of a New Section, all initiation fees of new members affiliated with that Section shall be remitted to that Section in full.

B-20 In the event of resignation from membership, the member shall not be relieved of the payment of any dues in arrears. All resignations shall be submitted in writing to the Executive Secretary of the Society or to the Secretary of the Section with which the member is affiliated.

B-29 In the event of a vacancy occurring on the Council for any reason, the successor shall be selected by the Board of Directors of the Geographic Section in which the vacancy occurred if the balance of the term is less than one year. If the unexpired term shall exceed one year the new National Director shall be elected by the membership of the Geographic Section in accordance with Article VII of the Constitution and By-Laws.

The Council shall appoint a permanent, full time Executive Secretary.

Under the direction of the National Council the Executive Secretary shall:

I. Promote the objects of the Society to the fullest extent.

He shall be responsible for developing the Society along the lines outlined in the Constitution and By-Laws.

He shall be alert to ways and means of improving local section activities, conferences, and the SPE JOURNAL, and all other activities of the Society.

II. Manage all of the affairs of the Society.

He shall be responsible for the
collection of all monies due the Society.
depositing of such monies to the appropriate bank accounts of the Society.
maintaining of appropriate books of accounts of the Society.
disbursement of the Society's funds and for preparing quarterly and annual financial reports from the Society's book of accounts.

He shall, with the approval of the National Council, employ such persons as are necessary to conduct the Society's affairs at salaries approved by the National Council.

He shall supervise the work of all employees of the Society and be responsible for the maintaining of appropriate employee records.

He shall maintain full records
of the minutes of all meetings of the Society.
of all correspondence of the Society.
of all memberships in the Society and
of all other official records of the Society.

He shall have charge of and be responsible for the properties and quarters of the Society.

He shall make and present an annual report at the annual meeting of the Society.

He shall attend all meetings
of the National Board of Directors,
of the National Executive and Finance Committees
of the Society's membership and he shall be an ex officio member of all national committees and attend as many national committee meetings as is possible.

He shall be the official representative of the Society in all business affairs of the Society.

Such Executive Secretary shall perform such other duties as may be assigned by the Council from time to time. Such Executive Secretary and any other agents or employees shall be bonded at the expense of the Society in such amounts and with such surety as the Council may direct.

He can be removed from office only by a two-thirds vote of the entire Council and then only for inability to fully and satisfactorily discharge the duties of his office, moral delinquency, incompetence, dereliction of duty or malfeasance of office.

B-43 The Section Secretary shall notify the Offices on or before January 1 by first class mail the name of the newly elected National Director from their Section. The Executive Secretary shall announce the names of all newly elected National Directors in the Official Publication.

B-54 The Secretary shall keep the minutes of all business meetings of the Society and of all meetings of the Council, keep a proper record of the same and submit a transcript of the minutes of each such meeting to each director; he shall keep such books and records as may be required by the Council, and generally perform such duties as required by the Constitution, By-Laws and Rules and by the Council.

B-55 & 56 The Treasurer shall report on the financial condition of the Society at every Council Meeting, shall present such statements of the financial conditions as required by the Constitution, By-Laws and Rules and shall perform such other duties as may from time to time be assigned to him by the Council.

B-57 All checks and drafts for the payment of money shall be signed by the Executive Secretary and co-signed by the Treasurer.

B-58 The President shall be authorized to co-sign checks and drafts but he shall perform such function only in the absence or inability of the Executive Secretary or the Treasurer.

B-59 omit

B-105 After December first but prior to the Section's Annual Meeting the Directors shall hold a meeting to elect the Officers for the following year. They shall elect from its members a President, Vice President, Secretary and Treasurer, and the latter two may be combined. The new Section Officers shall take Office immediately after the Section Annual Meeting serving for a period of one year and/or until their successors are elected and the President and Vice President shall not be eligible for re-election to the same Office within one year after the expiration of the term for which they were elected. Officers shall be eligible for re-election if they have not served a full term. The Treasurer shall be eligible for re-election if bonded. The election of Section Officers shall be by secret ballot, and an affirmative majority vote of the Section Directors shall be necessary to elect. The retiring Section President shall become a Director-at-large for a period of one year at the end of his term of Office.

B-117 Section Nominating Committee shall consist of five members affiliated with the Section, one of whom is a Section Director whose term is not expiring, and shall nominate candidates for election as Section Directors as provided in B-94 hereof. And shall nominate candidates for National Director if that term of office is vacant.

B-125 Each Section shall use only such uniform stationery, forms, etc., as shall be approved by the Council and as may be supplied by the Executive Secretary of the Society at cost plus a handling charge of fifteen per cent. This provision may be waived by the Council if conditions are deemed to warrant such action.

B-126 Each Section may adopt its own by-laws for the conduct of its local affairs; provided that they are in harmony with the Constitution, By-Laws and Rules of the Society, and that every publication of such Section by-laws shall be prefaced with a copy of this paragraph (B-126) of the By-Laws of the Society; and further provided that no such Section by-laws shall be effective unless and until they are recommended by the National By-Laws Committee and approved in writing by the Section Board at any duly held meeting by an affirmative vote of two-thirds of the Section Directors present, and such amendments shall become effective upon the recommendation of the National By-Laws Committee and the written approval of the Council.

P. L. Underwood

Executive Secretary

The State of the Society

Frank W. Reinhart

President, Society of Plastics Engineers, Inc., 1955
Chief, Organic Plastics Division
National Bureau of Standards

This article is the text of the address given by retiring President Frank Reinhart on the occasion of the Banquet at the Annual Technical Conference of the Society of Plastics Engineers, held last January in Cleveland.

THE SOCIETY OF PLASTICS ENGINEERS has grown and developed to the extent that it is no longer a fledgling. We have emerged from adolescence into adulthood — young, vigorous, ready to take our place beside our older brethern engineering societies. This development has been obtained through the blood, sweat, and tears of many members of our society. There have been disagreements, arguments, frustrations, disappointments, and problems of many kinds, but there have also been joys, fellowship, and solace in working with our fellow plastics engineers for a worthwhile cause. We have all had to give and take and submerge our individual prides and ambitions. Probably no one individual feels that as a society we have always done the right thing. However, since we are a democratic body we have always tried to follow the will of the majority. Your officers and committeemen have backed these decisions of the majority even when they personally would have preferred another decision. I know this has happened often in the last two years, during which time it has been my privilege to serve as your National Secretary and National President.

Our society has become so large that it is difficult if not impossible for most members to become acquainted with all its problems and ramifications. Therefore, the National Council informally requested that the outgoing President present a message on the state of the society at the Annual Technical Conference each January. I am the guinea pig for this experiment.

The purpose of this message is to acquaint you with the accomplishments during the past year and with the problems that still face us. If done properly, this should serve to orient you with respect to some of the work that lies ahead. It is hoped in this manner to make our operations smoother and more efficient.

Membership

The Society of Plastics Engineers is an organization of individuals; each man represents himself. It is an organization that endeavors to help each member maintain his dignity and freedom of thought in the development of his profession and his talents. Our members are the most important part of our society. Consequently, membership has been chosen as the first item of major importance in this message to you.

The membership on December 31, 1952 was about 2,100. On this same day in 1953, the membership was about 2,600, in 1954 it was about 3,200 and in 1955 it was about 4,300. As of tonight the membership roster and applications being processed totals 4,766. The increases in membership are 20 percent in 1953, 25 percent in 1954, and 30 percent in 1955.

On December 31, 1952, there were 30 sections. Four of these have fallen by the wayside and ten sections have been added since 1952. Thus, we now have 36 vigorous growing sections. Discussions are underway with various groups concerning the formation of seven more sections. The National Council has developed an evaluating procedure so that sections will not be formed unless they have the strength to survive and the potential to grow.

Finances

Any organization has expenses and consequently must have an income to pay these expenses. Finances are thus an important part of our life blood. All members realize this since we all pay dues and discuss "what do we get for our money." Your officers and directors know it, too, because they not only pay dues but they are con-

stantly spending time and more of their own funds trying to get the members more for their money.

Some figures may be of interest. On June 30, 1952, the close of the fiscal year, we had a net worth of about $2500. On the same day in 1953, the net worth was about $5500, in 1954 it was about $11,000 and in 1955 it was about $12,000.

Our expenses for the fiscal year closing June 30, 1952 were about $22,000. For the fiscal year 1953 the expenses were about $32,000, for 1954 they were about $46,000, and for 1955 they were about $61,000. It is estimated that our expenses for the fiscal year 1956 will exceed $80,000. In the past three years expenses have quadrupled and our membership has doubled.

During the past two years, your officers and National Committeemen have been studying ways and means of increasing our income so that our activities could be expanded and so that our ever increasing expenses could be met. Many of these means have been adopted and have helped. However, the additional income has not been sufficient to warrant the modest expansion of our activities that many believe to be necessary.

SPE Journal

A review of the back issues of the SPE Journal shows an increase in the number of pages printed each year and in the quality of the articles printed since 1952. During the fiscal year 1952 the SPE Journal issued 276 pages; in 1953, 446 pages; and in 1955, 496 pages.

During the past year, the National Council, the Publications Committee and the Editor reviewed the problems involved, made detailed plans to swing again to newer heights, and these plans are being put into operation during 1956. We have engaged a professional agency to handle our advertising and to give consulting advice on other aspects of the Journal. In addition the SPE Journal will have 12 issues for the calendar year beginning in 1956 and we expect to issue about 800 pages, an increase of over 60 percent.

Education

Through the efforts of the National Education Committee and the activities of some sections, advances in furthering education in plastics engineering have been made steadily. During 1955 this pace was accelerated and the results will be presented in publications in the near future. Problems concerned with registration and standards for plastics engineers are being studied.

Professional Activities

The professional activities of our society were spotty until 1954. Some sections and the National group were quite active from time to time; other sections did little or nothing. In 1954, the National Professional Activities Committee was reorganized and expanded. This rejuvenation resulted in much increased endeavor. The activities were organized so as not to compete with other groups already underway but along new and different lines. Cooperation with other groups was stressed. This increased activity continued through 1955 and has resulted in the initiation of actual work on a series of detailed engineering books on specific phases of plastics. The work on one of these volumes is well underway. A little work from many of us will make this activity a success. If you are not helping, see your National Councilman about getting in and doing your share.

Constitution and By-Laws

During 1955, some parts of the by-laws were revised and work initiated on revising some parts of the constitution. An overall review and revision of both documents, mainly of a clarifying nature, is underway.

Meetings

A group has been working on developing permanent plans for handling national technical meetings. Means are being considered to have much of the routine of the annual technical conferences eventually handled by the National Office. A series of area symposia on specific technical subjects was planned. The first experimental symposium on plastics in packaging was held by the New York Section a few months ago. Two others are being planned.

National Council

The responsibilities of the National Council have grown with the growth of the society. It became apparent in the latter part of 1954 that a body as large as the National Council could not handle all the detail required in a one day session each quarter. During 1955, more responsibility was placed on the National Committees to study detail and make positive recommendations for action to the National Council together with a summary of the points for and against the recommendations. This method of operation has been very successful. It has made it possible for the National Council to complete their business in a reasonable time and to give consideration to further planning and development.

Executive Committee

The activities of the Executive Committee have varied from time to time. In the last two years it has been used as an agenda review board to help sift arguments prior to meetings of the National Council and has been very helpful. However, this is not the most effective use of this body. It could probably be used to more advantage to handle some of the affairs that the National Council now handles, provided that the National Council delegates the authority in each case.

During 1955 we made long strides in building our society and in improving our operations. It is realized that this has been true every year for the past several years. The same will occur next year under our new president. Our past advances have resulted from the combined work of many of our members; likewise the extent of our advancement in the future will depend largely on the combined efforts of many. Without the sacrifices of many our achievements would have been small. Let us continue to give our new officers the fine help and cooperation you gave the past officers so that we may continue to develop further.

I wish to thank my fellow 1955 officers, the members of the 1955 National Council, the members of the National Committees, and the members at large for the help and encouragement you gave me. It has been a privilege and an honor to serve you.

Industrial Literature

Boron Polymers

Research in the fields of boron polymers, high-temperature resistant copolymers, and methods of curing glass-cloth reinforced laminates at room temperature are described in three Air Force studies just released to industry by the Office of Technical Services, U. S. Department of Commerce. These are;

RESEARCH ON BORON POLYMERS, Part II, Polymer Studies. Rutgers University for Wright Air Development Center, U. S. Air Force. May 1955. 85 pages. (Order PB 111-892 from OTS, U. S. Department of Commerce, Washington 25, price $2.25.)

RESEARCH ON THE PREPARATION AND PROPERTIES OF HIGH-TEMPERATURE RESISTANT COPOLYMERS. George Washington Carver Foundation for Wright Air Development Center, U. S. Air Force. May 1954. 23 pages. (Order PB 111-765 from OTS, U. S. Department of Commerce, Washington 25, price 75 cents.)

CURING OF VOID-FREE GLASS-CLOTH - REINFORCED LAMINATES AT ROOM TEMPERATURE. Forest Products Laboratory, U. S. Department of Agriculture, for Wright Air Development Center, U. S. Air Force. Mar. 1955. 35 pages. (Order PB 111823 from OTS, U. S. Department of Commerce, Washington 25, price $1.)

Fluorocarbon Coatings

Two classes of fluorocarbon coatings, whose properties single them out for use under the most severe chemical, electrical and physical conditions, are discussed in a new, 8-page report, "Fluorocarbon Dispersion Coatings."

The report compares, for the first time, detailed technical data on polytetrafluoroethylene (Teflon) and polymonochlorotrifluoroethylene (Kel - F, Polyfluoron and Fluorothene) coating materials and their resultant "baked-on" protective films.

"Fluorocarbon Dispersion Coatings" by Gene Bartczak provides information available on specifications and properties of "primer" and "finish" dispersions formulated, their handling, and types of application equipment required. Materials which can be coated, recommended techniques of application and "curing" for optimum results are also discussed. Physical, chemical resistance and electrical properties of finished, fused films are presented, together with recommended coating thicknesses for typical anti-hesive, thermal, anti-corrosion, electrical and other applications.

Copies of "Fluorocarbon Dispersion Coatings" may be obtained by writing to Gene Bartczak Association, 119 Soifer Avenue, North Bellmore, L. I., N. Y.

Automatic Deflashing

Automatic pellet deflashing of thermoset molded plastics and laminated plastics is treated in a new piece of literature available from Wheelabrator Corporation, 1258 South Byrkit Street, Mishawaka, Indiana. Four illustrated case histories are presented, showing how the automatic pellet deflashing process works, some typical parts from the range of work done by this process, and some performance rates. Savings obtained due to the adoption of automatic deflashing are also presented.

Kel-F Elastomer

The properties, applications, compounding, vulcanization, and fabrication of KEL-F Elastomer—a fluorocarbon rubber with outstanding resistance to heat and corrosion — form the subject matter of new companion brochures published by The M. W. Kellogg Company.

The first of the booklets, 16 pages, is designed for those who might use or specify the elastomer, which is supplied to industry in two grades of gum, differing in processing characteristics and vulcanizate properties. This brochure is devoted primarily to the gum characteristics and properties of the resulting vulcanizates, including physicals, thermal stability, water absorption, gas permeability, low temperature behavior, electrical values, and chemical resistance.

Copies of these brochures are available from The M. W. Kellogg Company, Chemical Manufacturing Division, P.O. Box 469, Jersey City 3, N. J.

Lucite for Lighting

A brochure is available concerned with the properties of "Lucite" acrylic resin and the applications which are being found for it in the field of lighting. Much of the data it contains is being released for the first time.

Gering Products, Inc., Kenilworth, New Jersey "Pioneers in Modern Plastics for over 30 Years" have just announced that they will market a new extruded Polyethylene moisture-vapor barrier film, called GER-PAK, through building supply wholesalers, in light and heavy construction fields.

The new moisture-vapor barrier film which is available in widths up to 20 feet; and wound on rolls of 100 linear feet or more, in thicknesses of .002", .004" and .006" and heavier, is available in two colors, Black and Transparent. Complete details and free samples on request.

Moly-filled Nylon

A "moly" filled nylon molding powder, trademarked NYLATRON GS, is described in a new bulletin available from National Polymer Products, Inc., Reading, Penna.

The bulletin explains how the field for molded nylon applications is expanded due to the superior wear and frictional properties of NYLATRON GS, along with its resistance to heat distortion and expansion. Test data is included.

The compound powders are reported to be readily moldable in equipment used for standard types of nylon.

Petrothene Resins

A revised edition of the brochure "PETROTHENE (R) Polyethylene Resins" is now available from U. S. Industrial Chemicals Co., Division of National Distillers Products Corporation, 99 Park Avenue, New York 16, N. Y.

In addition to the information contained in the original edition — on general polyethylene properties, method of manufacture, uses, methods of processing and fabrication — the new brochure includes tables on: properties of the PETROTHENE 100 and 200 series resins; formulations of PETROTHENE 300 series electrical grade resins; typical electrical, thermal, chemical resistance and film permeability properties of polyethylene.

Material Compatibilities

The largest, most comprehensive list showing compatibility or non-compatibility of reagents to such thermoplastic materials as polyethylene, non-plasticized polyvinyl chloride, high impact polyvinyl chloride, and high tensile high temperature polyethylene, has been developed in booklet form by the American Agile Corporation, Maple Heights, (Cleveland) Ohio.

Copies of the free literature may be obtained from the American Agile Coropration, P. O. Box 168, Bedford, Ohio.

THE INJECTION molderscope

By A. R. Morse
President, Injection Molder's Supply Co.

The Injection Molderscope solicits articles on any phase of injection molding from anyone who has ideas they want aired. We want stimulating articles and comments from anyone that can be adapted for publication. So let us hear from you — on machinery, on powders, on molds — it is your chance to be heard.

Injection Molding of Polyethylene

The foregoing articles have discussed some of the problems encountered in molding polyethylene. Many molders familiar only with the older low melt index materials may have wondered what this series of articles was all about, because no distinction was made between grades of polyethylene. Actually, a discussion of the effect of the various melt indexes and varying material densities of polyethylene on molding was postponed in the hope that one of the material companies could be persuaded to contribute a column on the subject, but we could not get it cleared by "legal," so I'll bumble thru it myself.

You can no longer consider polyethylene as one homogeneous material type. It is now available in a wide range of what we might call flow properties, ranging from soft to hard, in a general way only, analagous to the range of flows between say an S-4 and an H-4 acetate. With a low melt index of between 8-10 and thereunder, your material is somewhat tougher to mold, requires more heat and pressure, and does not decompose so easily during molding. It also has a duller finish and requires a hotter mold temperature which of course bespeaks a longer cycle. It is slightly less flexible, but only relatively so; and it is somewhat tougher and resists stress cracking.

With a high melt index material such as has found wide acceptance in the mid-west molding area you get a better, glossier finish. Your material is noticeably easier to mold. You can shoot larger shots at lower pressures and run the mold much cooler, even to chilling it. Molders have almost without exception increased the results they could get with a given machine over the older powders. Offsetting these very attractive advantages is the tendency of the piece to be a little more flimsy, but more important is an increase in stress cracking, and the appearance of carbon flecking unknown in some sections of the country, like California, where I understand experience has largely been limited to the low melt index materials of around 12 and under.

Between melt index 20 and say 8, it is virtually impossible to tell the various flows apart by visual inspection, or feel, or flexibility. The marked benefits of using a high melt index of say 20—the unexpected ease of molding a 22 oz. shot on a 16 oz. press, the faster cycle, the better finish, are undeniably attractive—but at the present stage of our industry's experience it appears that stress cracking and black flecks may well force a gradual retreat down the melt index scale until a level is found where the more serious disadvantages begin to decline. This will mean use of larger machines and better heating cylinders on existing presses to give the same high poundage per hour that could be achieved comparatively easily with high melt index powders on smaller machines. It will mean exacting studies in quality control, in temperature and pressure settings, and in mold temperature control because while stress cracking may be inherent in a specific powder, nevertheless it can definitely be minimized by good molding techniques. And where it does not exist in a material at all (as is most often the case) unfortunately bad molding techniques like incorrect press rating, too high heats, too fast cycles, can mold the tendency to stress crack right into a perfectly good batch of material. The material supplier then has the invidious, difficult and ticklish task of proving the poor treatment of his powder by his customer (the molder)—a job that has taxed some of the oldtimers in the material game and prematurely aged some of the newcomers. The machinery people too have been called to task to account for decomposition which has not been the fault of the cylinder or of the powder, but merely of the excessive demands made by the molder seeking to enjoy the maximum, and sometimes almost intoxicating benefits of the high index powders. Considerable impetus, however, has been given to heating cylinder design by the problem as has been mentioned in an earlier article.

One might ask why a high melt index powder could not be run safely at a lower heat to get rid of carbon type decomposition, but it does not seem to follow for several reasons—it resists melting, molds won't fill, wrinkles may develop. The trouble persists in spite of various heat settings, probably due to the basic nature of the material about which the molder at the present time can do very little except experiment with lower melt ranges.

Now to complicate the picture still further, the various melt indexes of a given polyethylene are being made available in various densities which also affect molding properties. As the material people learn more about polyethylene, the picture is becoming more involved, not less. The injection molder is faced with an ever-widening complex of material types, grades and flows. However, the added material grades are very definitely expanding the applications of injection molded polyethylene because of the added advantages of the tougher new powders which are flexible, yet resist stress cracking, and which can stand ever higher heats.

The purpose of these recent articles has been to call attention to the fact that while polyethylene has been responsible for a vast expansion of our injection industry similar to that caused by polystyrene in 1946-7, nevertheless if it is improperly selected, poorly molded, and badly applied it can back-fire on us just like the lamented plastic toy bombshell of the late forties that gave all "plastics" such a bad name among toy buyers.

Chemical Statistics Book

Publication of "Statistical Summary No. 1," first supplement to the fourth edition of the "Chemical Statistics Handbook," was announced here today by the Manufacturing Chemists' Association.

The supplement, first of a new series of chemical industry statistical summaries, contains up-to-date information in tabular form on wage, hour, employment, production and price trends in the chemical industry as compared with all manufacturing, through October 1955.

Copies of "Statistical Summary No. 1" are available at 60c each from the Manufacturing Chemists' Association, Inc., 1625 Eye Street, N. W., Washington 6, D. C.

"Statistical Summary No. 2" is scheduled to be published in the middle of the year, following completion of the 1954 census of manufactures.

The original basic reference work, the 412-page "Chemical Statistics Handbook," was published in June 1955. It contains a wide variety of official information and statistics.

NEWS of the industry

Wyatt's Plastics

Wyatt's Plastics, Inc., a new company in the plastics field, has completed its plant in Houston. Its foremost activity will be custom molding of plastic and rubber products. In addition, it will offer engineering and technical assistance in determining the feasibility of making finished products from plastics, as well as assistance in economical design of a product.

Wyatt's Plastics, Inc. is a subsidiary of Wyatt Metal & Boiler Works. The new plant adjoins the site of the parent organization with its offices at 5928 Katy Street, Houston.

Kennerley-Spratling

Kennerley-Spratling, Inc., a new plastics molding firm, announced today that production was under way at their new plant at 1456 Fourth Street, Berkeley. The new firm is headed by Fred L. Kennerley, President, and Ernest N. Spratling, Vice President. Both principals have had more than 25 years' experience in the plastics industry, and have worked together for the past 12 years as general manager and plant superintendent at American Molding Company of San Francisco.

Postforming

A new and revolutionary type of Increment Postforming equipment, known as Thermobond, is now being offered to fabricators by the R. A. MacDonald Company of Sun Valley, California. It is believed that this equipment will obsolete all other equipment in the postforming field because it has so many unique and important features.

The postforming processes using this equipment are covered by U. S. Patents owned and administered by North American Aviation, Inc., Los Angeles, Calif. For the name of your nearest Thermobond dealer write R. A. MacDonald Co., 7727 Case Avenue, Sun Valley, California.

Silicone Rubbers

Two new silicone rubber compounds which fabricators can use for rapid one-step thick section curing are now available in commercial quantities.

Known as "Union Carbide" K-1025 and K-1028 Silicone Rubber Compounds, they are prepared by Silicones Division, Union Carbide and Carbon Corporation, and come in neutral or red color. Designed for general purpose use, K-1025 and K-1028 meet or exceed Aeronautical Materials Specifications (AMS) and specifications of the American Society for Testing Materials (ASTM).

Data sheets on each of these two compounds are available by writing to Silicones Division, Union Carbide and Carbon Corporation, 30 East 42nd Street, New York 17, New York.

Precision Plastics

A 15,000 square foot addition to the manufacturing plant of Precision Plastics Company, 4655 Stenton Avenue, Philadelphia, will increase Precision's scope of activity in the plastics industry, according to company president, Edward W. Danien.

Improved Machinery

Improved Machinery Inc., Nashua, New Hampshire has elected George W. Whitehead as Vice President — Plastic Machinery Sales.

Mr. Whitehead joined the company in 1944 and has been Salesmanager — Plastic Division since 1949. He is a graduate of the University of Nevada, class of 1927. He is a member of the Society of the Plastics Industry and the Society of Plastic Engineers and American Chemical Society.

Acrylic Price Down

Reductions in prices of acrylic products, ranging up to 9½%, were announced, effective today, by Rohm & Haas Company. Products affected are Plexiglas sheet, Plexiglas molding powders and methyl methacrylate monomer, an intermediate in the manufacture of Plexiglas and related products. These reductions follow decreases announced last December on molding powder and monomer.

Rainville Appointed

The Vacuum Forming Corporation, 76 South Bayles Ave., Port Washington, N. Y., manufacturer of heavy machinery used to stamp or form plastics, has appointed The Rainville Company, 647 Franklin Ave., Garden City, N. Y., as its sales representative in the New England area and in northern New Jersey and New York State. The Corporation's brand name is "VACFORM."

Interplastics Corp.

Gerald F. Bamberger has resigned as Executive Vice President and General Manager of A. Bamberger Corp. and American Molding Powder & Chemical Corp., Brooklyn, N. Y., to form a new company which he will control and of which he will be the President. Henry F. Meckauer, formerly Export Manager of American Molding Powder & Chemical Corp. has joined Mr. Bamberger in the capacity of Vice President.

The new firm will be known as Interplastics Corporation with offices at 654 Madison Avenue, New York 21, N. Y. The telephone number is Templeton 8-0574; the cable address is "INPLAKO."

Interplastics Corporation will supply a complete line of thermoplastic molding powders, resins and raw materials, both for the domestic and overseas plastics industry.

Isocyanates Produced

The Du Pont Company announced today that its new isocyanates plant, geared to manufacture 25,000,000 pounds of these versatile chemicals a year, is now in production.

The new plant is at the company's Chambers Works at Deepwater Point, N. J., and currently employs more than 100 people.

EPON Price Drops

Shell Chemical Corporation has reduced the price of its EPON Curing Agent C-111 from 80 to 63 cents a pound. The reduction was brought about by lower manufacturing costs, according to George W. Huldrum, Jr., chemical sales division manager.

Barrett Appointment

Announcement of the appointment of John C. Esher as Assistant Sales Manager, Chemical Sales Department, has been made by Barrett Division, Allied Chemical & Dye Corporation. He will be in charge of plasticizers, naphthalene, resins and other coal-tar chemicals.

Foundry Plastics

Practical advice on production of dimensionally stable foundry tools at considerable savings of time and money is contained in "Plastics in the Foundry Industry," a technical bulletin issued by the research laboratories of the Marblette Corp., 37-21 Thirtieth St., Long Island City 1, N. Y.

Barrett Promotes

The appointment of J. E. Shand as Assistant to L. W. Miller, Manager, Chemical Sales, has been announced by Barrett Division, Allied Chemical & Dye Corporation of New York.

SPEAKING OF EXTRUSION

Edited by R. D. Sackett
Technical Service Associate
Monsanto Chemical Company
Springfield, Massachusetts

Considerations in Extrusion Equipment Selection

Armand Vallieres
Project Engineer
Prolon Plastics Division
Pro-phy-lac-tic Brush Co.
Florence, Mass.

With an increasing number of concerns supplying extrusion equipment, the problem of equipment selection is becoming steadily more difficult. This article, without attempt to recommend one construction over another, discusses some of the factors that should be weighed to make an intelligent selection of extrusion equipment regardless of its intended use. The weight that will be given to the various factors will depend to a large extent on the end use involved.

OUTPUT

A primary concern in the selection of equipment is the matter of output. An estimated plasticizing capacity is normally supplied by the equipment manufacturer. This figure is given merely as a rough indication and should be used only as a guide.

The output of an extruder is based on a number of factors such as screw design, barrel length, rpm, material and die design.

Let's look briefly at each of these items and what their importance is with respect to machine selection. It should be emphasized here that output by itself is of little importance unless some quality level is established. As quality becomes more important, some reduction in output must be expected in most cases. It probably also should be pointed out here that best operating conditions are normally obtained at something considerably under the maximum output of the equipment.

There is a difference in opinion among many as to whether or not screw design should be a factor in machine selection. Screw design is readily changed and nearly any screw that will work in one machine can be made to work in another machine. It should be realized that optimum screw design will, however, differ depending upon the material and individual job requirements.

The effect of barrel length is also an important consideration with respect to output. In many cases, longer extruders, on the order of 20-1 Le/D will result in either increased output or improved quality or both. The slight additional cost is usually warranted.

The rpm has a major effect on the output of the extruder, and any comparison with respect to output must, of course, be considered on the basis of rpm. One should determine probable rpm's to be run and select equipment capable of operating at the maximum and minimum levels established.

The plastic material involved and the die design, although they will affect output, do not normally enter as a factor in machine selection except in special cases where chemical resistance might be involved.

MECHANICAL

Probably one of the most important considerations under the mechanical features of the equipment is the type of gear reducer which is supplied. The gear reducer is the heart of the mechanical end of the machine and must be built sufficiently strong to carry the necessary loads smoothly, and for this reason the following considerations are suggested; the type and gear design, speed ratio, whether a herring bone or worm gear, type of bearings, thrust sleeve and oil seal, maintenance requirements, accessibility of the drive transmission for periodic inspection and replacement. Cost, of course, also is an important consideration, but should be considered in light of the above requirements.

Another important decision with respect to machine selection is the type of drive purchased. All extruder manufacturers supply equipment with either a mechanical type variable speed drive or an electrical variable speed drive of the AC-DC type. The cost of the electrical drive is higher, but is somewhat more versatile and exact in its operation. In some cases, single speed drives or three speed drives are desirable, and this will depend to a great extent on the type of service which the equipment will receive.

The following is suggested to evaluate the above:

1. Type of motor, its horsepower rating, torque, speed range, electrical requirements, cycle current and number of phases, watt-load.
2. Type speed indicator (tachometer) and ammeter for motor.

The feed opening should be examined as to its size and shape. It is generally considered that the hopper opening should be at a minimum equivalent to one diameter of the screw, and there are some who prefer that it should be as large as $1^3/_4$ diameters. For normal feeding operations, a single diameter is sufficient. Where difficult feeding problems are apt to develop, the larger size openings will in some cases be of assistance. This area is normally water cooled.

There is considerable uniformity amongst extruder manufacturers as to the actual construction of the extruder barrel. In most cases, Xalloy liners are used. When chemical resistance is a problem, special liners may be required. Where material containing volatiles are involved, provisions should be made for venting. In some cases, the liner is pressed into the cylinder. In other cases, a single integral piece is used. It is claimed by many that the integral unit gives better heat transfer. Consideration should be given to the number of sections in the cylinder assembly and how they are coupled together (whether with studs or bolts) and the area of the flange.

The die adapter, which can be considered a subsequent assembly, should be viewed with respect to the ease with which dies can be installed and removed from the head of the extruder. Points to consider are the type of linkage and number of bolts, etc. Accessibility of this assembly is also important, as it is frequently necessary to remove and replace screens in the strainer assembly or to clean the lead in section of the die.

The screw is considered the most important working part of an extruder inasmuch as it provides the mechanical mixing and forwarding action. There are many considerations that should be made with respect to the actual geometry of the screw. In this section, we will touch briefly on some of the major considerations aside from actual design.

The screw should be fabricated from a good grade of steel, whether stainless or alloy type. Surface finish treatment of the screw is important particularly the degree of hardness on

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AROUND THE WORLD

UNITED STATES

RUBBER AGE

January, 1956

Abstracter: James Harrington

RUBBER AND PLASTICS PACKINGS—Frederick C. Thorn—pg. 555-560

A discussion of the usual mechanical properties required of materials to be used in gaskets, discs, diaphrams, and sliding contact packings. The author points out that these applications require many special properties which are either not usually reported or not covered by any standard test procedure. Many specific examples of the use of plastic packings are included in this comprehensive article.

FRANCE

INDUSTRIE DES PLASTIQUES MODERNE

Vol. 7, No. 10 & Vol. 8, No. 1

Abstracter: Hans Mayer

VINYLITE COMPOSITIONS SUITABLE FOR COLD APPLICATION BY GUN

The composition and application of plastisol coatings to objects too large to be dipped or passed through applicators is described. The material developed for this process, "Parcoplast 300," has qualities similar to molded or extruded vinyl compounds if properly applied on top of the correct undercoating.

HIGH PRESSURE AND LOW PRESSURE POLYETHYLENE

The physical properties of products manufactured by different methods from both materials are compared and the production facilities for both types of materials in the producing countries are enumerated.

ELECTRICAL WIRING CONDUITS IN VINYL

The possibilities and execution of wiring through polyvinyl conduits are discussed.

GERMANY

KUNSTSTOFFE

January, 1956

Abstracter: Anne Schwend

PVC PLASTICIZERS FROM MONO-ALCOHOL-ESTERS — Wuerstlin and Hermann Klein

The structural principles of PVC plasticizers are systematically investigated as to their chemical modifications. The main characteristics: effectiveness, PVC diluent capacity and compatibility with PVC are compared. Since in 90% of today's customary plasticizers the ester group determines the diluent capacity and compatibility, investigations are based on aliphatic mono- and di-carboxylic acid esters.

CURING OF UNSATURATED POLYESTERS AT LOW TEMPERATURES—B. Berndtsson and L. Turunen

Kind and quantity of catalyzer and accelerator as well as duration and temperature of curing are investigated with a view to changes in the thermal and mechanical properties of the products concerned. Polyesters under consideration were both unfilled and reinforced. Curing temperatures ranged between 68 and 104°F., post-curing was effected at 158°F. Benzoyl peroxide-dimethylaniline catalyzer proved unsatisfactory for curing at low temperatures without post-curing. Catalyzer paste CHF + cobalt naphthenate (1 - hydroxycyclohexylhydroperoxide-1 + dibutylphthalate) yielded far better results for both unfilled and reinforced unsaturated polyesters. Light transmission was found decreasing with the increase in curing temperature especially when the polyester was applied at relatively high atmospheric moisture content. However, optical properties are not impaired if curing temperatures do not exceed 104°F.

TENSILE STRESS AND ELONGATION DIAGRAM OF POLYAMIDE—W. Weidmann

Tensile tests of Durethan BK polyamide show that particularly the first part of the test—from start to yield value—responds to any variations in environmental conditions and differences in material as well as testing conditions. Specimen may show different yield and stretching values though made of the same material in case their moisture content or elongation speed are divergent. Constant loads cause deformation at points far below the yield point without hope for resilience. Test results are enlarged upon and may be applied for polyamids of other makes, too. Any engineer may read off the required data from properly kept diagrams for manifold design applications.

EXTRUDERS WITH HI-SPEED SCREWS—Erich Beck

New extruder design principles are discussed: 1. Independency from dwelling time of plastic material in the barrel, normally required for heat transfer, is one of prerequisites. 2. Feed should be heated uniformly and evenly in all parts of barrel. No heating should take place at the internal surfaces of enclosing metal parts even if roughness or related unevenness should hamper the passage speed of mass particles. On the contrary, heat should be released through outer mantle into the open air. 3. Since the feed has to be kneaded and homogenized anyway prior to extrusion, sufficient mechanical energy may be applied for this preparatory job to melt the mass. Thus heat is generated in the mass itself, the best guarantee for even distribution of temperature. 4. To eliminate any deficiencies through inaccurate measuring of the temperature by thermostats, the energy supply is no longer controlled by the temperature but by the viscosity of the melt, the screw itself serving as feeler gauge. In case of increasing viscosity, the screw draws more energy from the motor and vice versa. Application of these principles permits to speed up the number of revolutions of the motor to such an extent that interswitching of gears becomes superfluous. Adjustable feed weighing and setting mechanisms for power consumption render obsolete speed controls and any temperature control device since a certain melt viscosity and the pertaining temperature adjust themselves. Several patents have been applied for for the principles described. A model extruder was built on this basis.

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SECTION NEWS

Edited by
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Western New England

Physicist Jules Pinsky Presents Talk On Effects of Coatings, Polymethylenes

Charles P. O'Donnell

"Effects On Polyethylene Packaging of Coatings and Polymethylenes" was the theme of a talk presented to seventy-five members of the Western New England section by Mr. Jules Pinsky, on the evening of February 1. The regular monthly meeting, held in the Terrace Room of the Bradley Field Administration Building, was treated to a crisp, authoritative report, with visual aids to accent the high points and a table display for post-presentation observation. Mr. Pinsky, Chief Physicist for the Plax Corporation in Hartford, Connecticut, gave a comprehensive talk on the polyethylene packaging picture, touching on the problems and faults peculiar to the polyethylene package, some of the work done by his organization with coatings and polymethylene to adapt these packages to broader areas of use, and a few of the pitfalls and snags to be alerted to in these adaptations.

Mr. Pińsky pointed out that the introduction of coatings and polymethylenes, (otherwise known as low pressure polyethylene), has already influenced future packaging planning. However, he strongly underlined throughout his entire report the need for careful evaluation and application to insure proper end-use of these plastics. But, with Plax' records showing only one out of two customer's products now able to use polyethylene packaging, their physicist feels that coatings will open new horizons for polyethylene packaging.

This low fifty per-cent application rate for polyethylene was due to chemical attack on the polyethylene, too high a permeability factor, package distortion, or causation of a greasy outer surface. Coatings overcame many of these deficiencies; of fifteen materials listed as normally non-packageable in polyethylene, thirteen of them could be packaged with liners. In some instances, coatings are needed by polymethylene to supply it with the proper packaging properties.

At this point, Mr. Pinsky explained that Plax feels it necessary to accent he difference between polyethylene and polymethylene properties and applications, hence their preference for the name polymethylene as compared to low-pressure polyethylene, linear polyethylene, etc. Using slides showing test results on actual samples and as projected on graphs, the speaker demonstrated differences in squeeze properties, recovery rate, and feel and opaqueness. These, in addition to chemical, permeability, and temperature resistance underlined this decision to differentiate, by name, between the two.

Throughout this section of his presentation, the Plax physicist devoted considerable time to explanation of, and applied uses for, the theories and formulae of his profession. In this area, the researchers found that by applying a positive polarity material to the non-polar compounds, such as polyethylene, an effective barrier for both polar and non-polar materials was the result.

The speaker reiterated the need for caution to avoid misapplication of new developments. He listed the following five features as test requirements the suppliers and users of packages should check carefully in regard to the intended application: chemical resistance, permeability, adhesion and flexibility, collapse prevention, greaseproofness.

In reference to adhesion, it was emphasized that the surface had to be treated before applying the coating and that "the degree of treatment is more critical than that for applying a printing ink." A report from a molding powder supplier referred to a patented treatment using chromic acid dip to oxidize the polyethylene surface.

Besides checking for properties peculiar to the item under test, Mr. Pinsky suggested checking for the following in a twenty-eight day shelf life test at both room temperature and 120 degrees Fahrenheit; weight loss, collapse, bulging, greasy outer surface, perfume odor difference, loss of flavor, chemical reaction, loosening of coating, flexibility, loss of effective ingredients, discoloration, pH change in contents, change in refractive index of contents, emulsion breakdown.

Another problem of the polyethylene packaging field remarked upon was the variations in polymethylene molding powders as received from the separate suppliers . . . even in various lots received from the same supplier. Here, again, the Plax physicist presented a check list, intended in this instance to bring out the large variations which, the speaker said, were often found in shipments of polymethylene received from molding powder suppliers; residual solvent, stress corrosion cracking, odor, effects of pigment, specific gravity variations, aging differences, miscellaneous.

In this test check list for polymethylenes, the "miscellaneous" category was considered the most important because of the number of unknowns in any new plastic.

The talk concluded on an optimistic note concerning the future of polyethylenes and coatings. But here, too, the plea was made to make haste slowly by careful engineering of the materials and through proper application of the end-use.

At the conclusion of his presentation, Mr. Pinsky held a short question-and-answer period which moved over to the table-display for the wind-up of this session.

Milwaukee

February Meeting Has Largest Group

W. H. Brueggemann

The February meeting of the Milwaukee Section of SPE proved to be the largest turn-out our society has had to date.

Mr. Robert F. Traflet, Technical Representative in Chicago of the Molding Division of the Bakelite Corporation, discussed the molding of phenolic resins and presented an excellent movie entitled, "Molding Phenolics." This described the various techniques and equipment necessary to mold phenolics along with examples of the finished articles.

Following the movie, the group toured the plastic molding operation of the Cutler-Hammer Corporation here in Milwaukee. This allowed the group an on-the-spot inspection of some of the molding operations seen in the movie plus a good display of the production of plastic items.

Continuing the excellent programs already held, the Program Chairman has retained Mr. Gorder Thayer of the Dow Chemical Company, nationally known authority on injection molding, as our next speaker for the March 13 meeting.

Eastern New England

Section Conducts Panel Discussion On Subject of Plastic Containers

Alfred I. Simon

A joint meeting of the S.P.I.-S.P.E. was held at the Hotel Beaconsfield in Brookline, Massachusetts, on Thursday evening, February 16, 1956. A group of approximately 130 members and guests attended. Included as guests were fifteen Lowell Technological students majoring in Plastics Engineering.

After a smorgasbord meal, a panel discussion was held on plastic containers with primary emphasis on the thin-walled ones. Jack Kavanaugh of Standard Tool Company discussed non-conventional molds for molding thin-walled (.014") containers.

Michael Merrill of Dow Chemical Company spoke on soft flow materials which can be used for high speed in conventional presses for the molding of thin-walled containers competing with paper containers. He mentioned that this soft flow material does sacrifice physical properties and that special molding machines utilizing stiffer flow material would produce parts with better physical properties.

George Whitehead of Improved Machinery Company talked about faster operating machines. After a great deal of experimentation, it was found that speed in closing of the mold and speed of injecting the material after locking the mold are the important factors in molding of thin-walled containers. However, there is quite a bit more to be learned about machines, molds and materials.

John Adamitis of Beacon Plastics spoke from the viewpoint of a molder of plastics.

The meeting was then turned over to a discussion including the audience and the panel. A partial summary of this follows:

A question of temperature control in the gate area produced the following answers:

1. The gate area should be centered and cooled
2. A beryllium copper insert for good heat transfer is used for the portion of the mold adjacent to the bottom of the container
3. A water jacket around the nozzle bushing is also used to control temperature in this area

Heat distortion is sacrificed with easy flow materials.

Factors in mold design for thin-walled containers:

1. A good mold may cost as much as 50% more than a conventional mold for heavy-walled sections
2. It must be ruggedly built in order to overcome the problem of shifting of the core

A disadvantage of a preplasticizing machine is that it is slower than a single plunger heating cylinder.

The determination of the number of cavities for a thin-walled container depends both on the wall thickness and the area. The thinner the wall the less the number of cavities; the larger the area the more chronic the conditions.

It was pointed out that speed of injection is highly important, since at low speeds the wall skins are high, the gate area is strained and there is not enough pressure at the opposite end of the gate; while rapidly filling the cavity will minimize the strains at the gate. The rate of injection and temperature of the mold, therefore, control orientation and strains in the molded part.

Other questions on transparency versus translucency in containers were discussed. A two cavity mold appears to be optimum for the molding of 16 oz. containers at present. An economical four cavity mold appears possible.

Heating cylinders are being studied to improve efficiency and reduce pressure loss.

Central Ohio

Jack Knight Speaks On Sheet Forming

Victor Hauprich

The February 21st meeting of S.P.E. was held at Reeb's Rathskeller with twenty-five members and guests in attendance and an excellent roast beef dinner was thoroughly enjoyed by all present.

Mr. Dixon opened the business meeting requesting individuals to introduce themselves. Bill Croll reported on the discussions at the recent National Council Meeting held in Cleveland.

Gene Cain introduced the speaker for the evening, Mr. Jack Knight of Fabri-Form Company, who presented an interesting resume of the many advantages and some of the pitfalls of the plastic sheet forming business. Mr. Knight displayed samples of vacuum formed sheet and, with the aid of slides, ran through some of the engineering considerations involved in supplying stress-free and dimensionally-stable parts. Careful heat control and cycle timing are among the many variables which are gradually bringing about the transition, in this field, from an art to a science.

Kentuckiana

Section To Present Achievement Award At May Meeting

R. O. Carhart

The regular monthly meeting of the Kentuckiana Section of the SPE was held on February 15, 1956 at the Kennel Club in Evansville, Indiana. We were pleased to welcome Don Korb, Werner Purtzer, Dick Major, Barney Derrington, Golden Kruse, of Crescent Plastics; Jack Hauke, Hoosier-Cardinal; Jerry Koofer, Benerson Corp., and L. Schmidt, Kent Plastics as guests, and hope to see them back again in the near future.

During the business meeting, the following information was presented on the Achievement Award which is to be presented at our May meeting to the member or members judged by the committee and Board of Directors to have made the outstanding contribution to the plastics industry. The committee to handle this award has R. R. Millar as chairman, with R. C. Peters and A. M. Varner as assistants. The qualifications for eligibility are that the person being considered be a member of the SPE attached to the Kentuckiana Section and that he have made a contribution to the plastics industry through any of the following: (1) design and development of tools, equipment or processes; (2) design and development of new products; (3) new plastic materials; (4) development of new applications and markets; (5) for work in the section or national organization. The award is to be designed by E. H. Roberts and is to consist of an appropriate plaque.

Brief discussions were held as to programs for increasing membership and for gaining publicity for our section and its members. It also was announced by Ken Erwin that the Board of Directors has agreed to sponsor two college professors as members, one from the Louisville area and one from the Evansville area. This is being done in an attempt to encourage universities and colleges to participate in the plastics program. It was pointed out that there is a great need for plastics engineers and for school programs to educate such engineers and technicians.

At the completion of the business portion of the meeting, Vice-president and Program Committee Chairman Clem Young introduced Mr. J. D. Hinchen of the Monsanto Chemical Co., who presented an interesting discussion on "Solving Plastics Production Problems Through Quality Control."

R. I. and S. E. Mass.

'Ladies Day' Scheduled For May; Educational Program To Be Next Fall

Glenn A. Tanner

The February meeting of the Rhode Island and South East Massachusetts Section was held Thursday, February 23rd, at the Wayland Manor, Providence, R. I. A good number of people turned out to see the compression molding films sponsored by Bakelite Corp., and hear the comments of their representative, Mr. Clifford Hawley. A fine dinner was preceded by a social hour, and followed by the business meeting and the film.

Members were sorry to hear that Mr. Robert Feuchter of Cranstom Molding Co., was moving to Cincinnati. Mr. Feuchter is one of our earliest members, having joined the organization in 1949, and has been extremely active in this section, since that time. He has held various offices, including the presidency. The group will suffer the loss of a man who has done so much to build the spirit of our organization.

Sydney Lohmann, Chairman of our Ladies Day Committee, announced that this year's ladies day will be held the third Thursday in May, at the Pawtucket Golf Club. This affair has become an annual event in our SPE section program and each succeeding year it has been a greater success. From the sound of the present plans, it appears that we can look forward to even a greater evening than ever before. Mr. Lohmann stated that he would like all members to keep in mind that they will be solicited very shortly for door prizes and favors for the ladies, and said that he would like all members to keep this in mind.

Mr. Howard Amster of Reliance Molded Products, and Chairman of our Educational Program, announced that plans were progressing rapidly for the plastic education program which will be introduced this fall. This will be the subject of the Directors Meeting, which will be held Thursday, March 1st, at Mr. Hugold Anderson's office at 7 p. m. Although this is officially our Directors Meeting, all persons interested in the Education Program were asked to attend. Also, he suggested that anyone having any literature, outlines, or suggestions that could be incorporated in or used as reference in this educational program, should send this material to him at Reliance Molded Products, Woonsocket, R. I.

Our Secretary, Mr. Charles Chrones, of Hassenfeld Bros., Inc., announced that our section has had four new members elected and accepted a transfer. The new members are:

Mr. Henry McVickers, Jr., American Cyanamid Co., Boston, Mass.; Mr. James E. Ebenholtz, Plastene Corp., Norwich, Conn.; Mr. Allen Cameron, General Electric Co., Taunton, Mass.; Mr. Emil E. Fischbach, Metals & Controls Corp., Attleboro, Mass.

The transfer is Mr. Louis Robbins of Modern Plastics Engineering Co., Taunton, Mass.

Several new applicants for membership were in attendance and two of these were fortunate enough to win the door prizes for the evening. The lucky persons were: Mr. Sam Cuddy of Rumford Plastics, Inc., East Providence and Mr. Thomas Cuddy of Cuddy & Herbert, Rumford, R. I. The two door prizes were donated by Mr. Clifford Hawley of Bakelite Co., and Mr. Howard Amster of Reliance Molded Products.

The Bakelite Co. Film was very instructive and offered much basic information on the terminology and problems involved in molding thermosetting material. By means of excellent drawings, they illustrated the differences between positive molds, flash molds, positive landed molds, and semi-positive molds. A good deal of information was given on the advantages, problems, and use of each type. Cutaway drawings of molds explained the difference in operation between compression molding, plunger molding, and transfer molding.

After the showing of the film, Mr. Hawley stated that this film and accompanying manual is available for other interested groups. Mr. Robert Feuchter assisted in leading the discussion that followed, which was quite lively and enjoyed by all.

Upper Midwest

Juras Is Speaker

Francis W. Brown

The Upper Midwest Section met February 20th, with thirty-five members in attendance. The speaker of the meeting was Appy Juras, Midwest Area Manager, of the Rezolin Inc. Mr. Juras, who has spent fifteen years in tool engineering and manufacturing, spoke on "Tooling With Plastics." He outlined the use of plastics in tooling particularly as applied in the Detroit area. The field is growing rapidly—4,000 men are now employed in shops in the Detroit area with an increase of 50% expected in the next two years. Since regular tool shops are not equipped for plastic tooling most of the thirty plastic tooling shops in the Detroit area are new. The low capital outlay of about $100,000 required for a plastic tooling shop compared to about $5,000,000 for a completely equipped tooling shop has aided growth.

Following Mr. Juras' talk Mr. Paul Becker displayed several examples of the use of plastic tooling in machine and assembly work at Minneapolis-Honeywell Regulator Company.

Membership Competition Chart

Section	Membership Chairman	Members July	Members Oct.	Quota To Go	Quota Met
Baltimore-Washington	B. E. Franklin	84	91	17	100%
Buffalo	R. A. Paumgartner	76	77	15	46%
Central Indiana	John E. Anderson	16	54	15	173%
Central Ohio	Wm. Croll	50	50	15	40%
Chicago	Earl Wilson	354	373	71	90%
Cleveland-Akron	Carl W. Virgin	219	233	45	109%
Connecticut	Lewis Pentland	102	110	21	38%
Detroit		201	216	40	83%
Eastern New England	Joseph P. Clancy Robert S. Ward	163	176	35	66%
Golden Gate	Leonard Faber	42	46	10	80%
Kansas City	Robert Thomson	52	52	15	93%
Kentuckiana	A. Roche	4	24		
Miami Valley	Charles M. Selz	99	105	21	38%
Milwaukee	Martin Bretl	42	43	10	180%
Newark	R. K. Louis	428	442	85	54%
New York	Edward L. Larkin	443	474	92	63%
Northern Indiana	John L. Haugsrud	22	23	10	210%
Northwest Pennsylvania	D. A. Leet	86	88	20	25%
Ontario	N. D. Hall	122	122	21	76%
Pacific Northwest		32	33	10	0%
Philadelphia	Fred Hillsley	230	249	47	96%
Pioneer Valley	Frank Z. Bailey		4		
Pittsburgh	Charles Snyder	61	61	15	46%
Quebec	J. Chapman	52	52	10	20%
Rhode Island & S. E. Mass.	Sydney Lohman	107	109	22	36%
Rochester	Albert F. Patterson	83	87	20	60%
St. Louis	Chris. Kacalieff	73	76	15	80%
Southeastern Ohio		43	43	10	40%
Southern California	Lawrence B. Green	138	150	28	100%
Southern Section	William B. Erb	60	62	15	40%
South Texas	Carl Eckenrod	41	41	10	80%
Toledo	Gunther Griefelt	66	70	15	53%
Upper Midwest	Orville Hultgren	69	75	15	127%
Western New England	Walter G. Clark	202	202	40	58%
Non Section		58	69		
TOTALS		3951	4182	839	73%

New York

Panel Compares Four Molding Processes As to Cost, Tooling

Jim Dugan

Over 90 members and guests attended the February 15 meeting of SPE's New York Section, held jointly with the Section's Reinforced Plastics Group at the Gotham Hotel in New York City. The meeting took the form of a panel discussion; comparing four molding processes with respect to their modes of manufacture, tooling required, and costs. Two items, a six by six-inch cone and an 18 by 24 by 12 inch box were chosen to illustrate the techniques in question.

Bud Ullman, Kuhn & Jacob Molding & Tool Co., was not too optimistic about the use of compression molding in either case. He felt the cone was definitely out. Cost would be the primary consideration here, since compression molding requires a large press and preformed material. Tooling could cost anywhere from $6-15,000 and, with a cycle time of six minutes, approximately ten boxes could be turned out in an hour. Even without considering rejects, and thermosetting material cannot be reused, Mr. Ullman estimated piece cost for a 1,000-unit run to be around $5.50. A 5,000-unit production would bring piece cost down to $5.25-5.35; however, mold amortization would necessitate extremely long runs to make compression molding competitive.

Injection molding was the method chosen by Saul Blitz of Tico Plastics. He also felt that the number of pieces was the primary factor in the case of the box. He estimated mold cost at $15,000, and brought up the question of delivery date—about 24 weeks. However, in 80 gage high-impact styrene, he estimated a unit cost of $2.11; $4.00-6.00 for butyrate, assuming the same cycles. The six-inch cone presents little problem, since the standard injection press opens 10 inches. Mr. Blitz felt the cones should be priced at 23c in styrene, 28c in acetate, and 40c in butyrate. For quantities above 5,000, he felt a two-cavity mold should be employed. This would give less shots per hour, but the higher production rate would bring the unit price for a styrene cone down to 19c.

Vacuum forming offers many advantages, according to Daniel Lewis, Durable Formed Products, Inc., depending on the number and the required delivery date. Tooling would cost only $85, and 100 boxes would cost around $200-225. Cost per unit for a 5,000 run was estimated at $1.95. Longer runs are not feasible, since delivery date would be about six months to a year, and the higher mold costs would be amortized. For the box, Mr. Lewis would use a high-impact copolymer sheeting. He felt that square corners should not be expected, if good impact strength and finish is desired. Tooling would run about $125, and the price per box, formed from ¼-inch sheet, would be $14.95; $13.00, for a 5,000 run.

J. D. Bassin, Borden Co., presented the case for reinforced plastics. He felt that the cone, being expendable, does not actually require the strength properties of reinforced plastics; however, its use would be quite feasible. For 100 cones, he would recommend matched plastic molds and room temperature cure. For 100-50,000 units, matched aluminum molds were suggested; chrome-plated steel molds for numbers in excess of 50,000. Plastic molds were not recommended for heat cure, since the expansion factor for plastic is about 50×10^{-6}. This, as opposed to 10×10^{-6} for steel. Estimates for 100 cones would run about $2.75 each. Matched aluminum molds would cost about $150, but the unit price would drop to $1.00. Boxes would be produced in the same type molds; plastic molds costing $250, and aluminum molds running about $1,000. Costs per box would be $9.25 and $3.75, respectively.

The New York Section welcomes the following new members: Peter Henry Merz, Samuel Eppy & Co., Inc.; Nicholas Meglino, Neo-Line Products Corp.; Frank Mazzarelli, Neo-Line Products Corp.; August M. Mazzarelli, Neo-Line Products Corp.; Matthew F. Antonovich, Advance Solvents & Chemical Div. of Carlisle Chemical Works, Inc.; Jack Emsig, Emsig Manufacturing Co.; William Bodenstein, Rego Insulated Wire Co.; Arthur A. Friedberg, W. Braun Co., Inc.; Prem Gary, International Balsa Corp.; Murray Nadel, Augusta Plastics, Inc.; Edward M. Bermas, Augusta Plastics, Inc.; Leonard Skriloff, Augusta Plastics, Inc.; Stanley Sapery, Augusta Plastics, Inc.; Lawrence R. Sparrow, Republic Aviation Corp.; Gerald Gross, Breskin Publications; A. J. Dragonette, Bakelite Co., Div. of Union Carbon & Carbide; Malcolm W. Riley, Materials & Methods Magazine; and Benjamin B. Kaplan, Benter Company.

Central Indiana

140 Journey To Anderson For Delco Remy Tour

C. R. Smith

On February 28th the largest gathering in the short history of the Central Indiana Section convened at the Anderson, Indiana plant of the Delco Remy Div. of General Motors for what proved to be one of the most interesting sessions to date. A total of 140 guests and members, some of whom had traveled literally hundreds of miles, were treated to a fine buffet supper with the compliments of Delco Remy before starting the evenings activities.

The group was officially welcomed by Mr. H. G. Riggs, Works Mgr., who outlined briefly the history and general operations of his Co.'s plastics departments. This briefing revealed the fact that the thermosetting molding department uses in excess of 600,000 lbs. of material a month in the daily production of approximately 600,000 parts, while the thermoplastic molding department uses an additional 115,000 lbs. of material per month.

The tour was accomplished by rotating two groups through each department. Guests were permitted free access to the plastics operations areas, thus providing an excellent opportunity for each person to observe the functions of most personal interest. Questions were answered by well informed and easily located guides. Of greatest interest in the thermosetting department was the newly developed automatic high speed plunger molding equipment as well as other Delco Remy designed and built press equipment, unique in the field. The thermoplastic department exhibited 22 injection presses operating on automatic cycling.

Mr. Gene Quear and his associates are to be complimented on the excellence of their arrangements. The entire tour was conducted with a minimum of confusion and most certainly contributed greatly to everyone's fund of knowledge as well as their interest in SPE activities.

This evening's meeting also served to introduce the Section's new Officers and Directors who are: Clifford R. Smith, President; Eugene C. Quear, Vice Pres.; William Millholland, Sec. & Treas.; David D. James, National Director; Harold Riley, Jr., Director; John Remley, Director; Stephen D. Ransburg, Director; Arthur B. Hitchcock, Director; John E. Anderson, Director.

Newark

Subject Is: 'Injection Molding Of Rigid and Non-Rigid Vinyls'

R. Bostwick

The regular February meeting of the Newark Section was held on February 8 with 110 members and guests attending the dinner. Wayne Schrag spoke briefly on the employment service he runs informally for the Section membership. Wayne certainly deserves credit for this unselfish undertaking. He reported that at the moment he has more jobs than applicants.

The subject for the evening was "Injection Molding of Rigid and Non-Rigid Vinyls." Mr. J. H. Malone of B. F. Goodrich Chemical Co. spoke on the rigid vinyls and Mr. J. H. Wilkinson of Bakelite Co. spoke on the non-rigid vinyls.

Mr. Malone explained that there are two types of unplasticized PVC. Type I is of normal impact (0.8 Izod) while Type II is modified to give higher impact strength (15 Izod). Type I has higher tensile strength and better chemical resistance than Type II. Mr. Malone showed a number of slides of molded rigid PVC applications, mostly in the pipe field, and then discussed molding. A stock temperature of 350-365°F is recommended for both transfer and injection molding. In transfer molding, the pigs are preheated to that temperature and pressures of 20,000-30,000 psi are used. In injection molding, pre-plasticizing units and specially designed heating cylinders are advised, again with stock temperatures of 350-365°F and injection pressures of 20,000-30,000 psi. In mold design, large gates and large sprues are recommended and chrome-plated molds. Mold temperature should be 130-140°F or the mold can be cycled. Where a core is used, control of core temperature is important. In conclusion, Mr. Malone felt that the combination of corrosion resistance, good aging characteristics, ease of handling and good strength properties inherent in rigid vinyls would result in substantial growth in this plastic in the next five years.

Mr. Wilkinson devoted his talk to the importance of restricted gating in the injection molding of plasticized vinyls, using for text and illustration the pioneer paper in this field "Restricted Gating," by R. Bostwick and C. A. Joslin. As introduction, the speaker cited the wide range of properties obtainable with plasticized vinyls and the recent price reductions amounting to over 30% on resin price in the past year. Restricted gating has been important in overcoming earlier deficiencies of elastomeric vinyls in molded gloss. It is considered that the restricted gate gives a "flash" frictional heat at the last moment before entering the cavity, thus improving molded appearance. Furthermore, cylinder temperatures can be lowered, with material heating looked upon as a two-step process—first the cylinder and secondly the restricted gate. Restricted gating, for this purpose, is defined as below .025" in diameter.

The speaker showed slides of a Bakelite laboratory mold design and various gating methods studied. The poorest results were obtained with a large gate of ¼" diameter. Better results were obtained with several restricted gating systems. The best was a gate .020" in diameter by 1/16" long with a well between the restriction and the actual entrance to the cavity.

Door prizes were donated by Parkway Plastics, Wheelco and F. W. Egan & Co.

Our best wishes go to Dick Goldrick who is leaving this area for St. Paul. Dick has been an active Section member for several years.

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Baltimore-Washington

Charles Stock Discusses Influence of Curing Conditions On Plastics' Fatigue

William C. Rainer

The first meeting of 1956 took place at the Langley Park Hot Shoppe near Washington, D. C. on January 10th. Forty-seven members and guests were present. Irv Wolock, newly elected president, called the meeting to order at 8:00 P.M. Frank Reinhart, national president and national councilman of the section, reported on national activities.

Mr. Charles Stock, Research Division of American Cyanamid Company was the speaker for the evening. His topic was: Influence of Curing Conditions on the Fatigue of Reinforced Plastics. Mr. Stock stated that polyester resins, reinforced with fiber glass, have been placed in direct competition with steel in certain areas. He reasoned that the glass supplies the strength while the resin distributes the shock. Mr. Stock also emphasized the importance of enhancing resin adhesion to the glass by the use of a size, e.g. vinyl silane. He went on to prove that sizing brings about a marked difference in performance after either a slow or a fast cure. Whereas the absence of size during rapid cure was conducive to failure of the piece, the use of size, however, was found to improve greatly its fatigue resistance.

In conclusion, president Wolock praised the outstanding work of Dan Nitzberg and Barney Franklin whose efforts were significantly conspicuous in the growth of the section over the past years.

Section Election Results: The following were elected to the board of directors: George Flanagan — B. F. Goodrich, and William C. Rainer — Crown Cork & Seal. Clare Milton — Eastern Venetian Blind was reelected to the board.

Officers for 1956 season are:

President, Irvin Wolock, National Bureau of Standards; Vice President, Clare Milton, Eastern Venetian Blind; Secretary, Nancy Rucker, Nixon Nitration Works; Treasurer, Bernard Franklin, Rohm & Haas; National Councilman, Frank Reinhart, National Bureau of Standards.

Southern

Report Given on Cellulose Ester

John W. McCauley

The February meeting of the Southern Section was highlighted by a report on cellulose propionate molding compounds. Several items of current society business also held the interested attention of the thirty-plus members present.

Dave Jones of the Market Development Division of the Plastics Division of the Celanese Corporation of America presented his paper on "Forticel," cellulose propionate molding compound, which he had originally read at the 12th Annual National Technical Conference of the S.P.E. in Cleveland during January 1956. As he explained it, cellulose propionate is another of the many advances in delivering an unusual balance of properties with the cellulosic family of thermoplastics. Currently three formulas of cellulose propionate are commercially available, varying in the level of plasticizer — with resulting variances in impact strength and stiffness. All three are characterized by a considerably lower level of plasticizer than previously available cellulosics, with resulting improvements for the trade in odor, fabrication, lacquering and cementing techniques as well as improved surface gloss.

"Forticel" is recommended for such applications as pens and pencils, telephones, knobs, housings, helmets and keys.

Mr. Jules Lindau, representative of the Southern Section to the national council of the S.P.E. as well as the recently elected vice president of the national organization, presented a brief review of the business meetings in Cleveland. His remarks were discussed with considerable animation and several recommendations were sent via him to the national body.

Mr. Clarence Ballentine, chairman of the Education Committee, reported on his recent activities with some suggestions for contacting universities and technical schools in the southern area.

Directors Named

R. R. Zisette has been elected a director and vice president-general manager of **Jessall Plastics** Incorporated, it has been announced by C. F. Norberg, president of The Electric Storage Battery Company, owner of the Kensington, Conn. concern.

At the same time, Norberg announced the election of R. S. Jesionowski, founder of Jessall Plastics, as a vice president and director. Other new officers of the firm, which makes standard and custom extrusions of high quality for chemical, aviation and other industries, are E. J. Dwyer, secretary; E. W. Williams, Treasurer, and M. G. Smith, comptroller.

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1 Subject—Government regulation—news item reads "The I.C.C. existing tariffs and rules regulating the transportation of water melons would fill a shelf 3 feet (or two water melons) long."

2 Subject—relative importance—news reports state that an Atlantic City amusement company operating an **illegal** numbers business is in trouble only with the Internal Revenue Service. Nothing is said about prosecution for operating an illegal business. Do we need tax money that badly?

3 Subject—social planners—The Vice-President of a large electrical concern states, "***We have to please people from their own standpoint. This means that more frequently than not, we have to help people change some of their present liking to liking what we have found sincerely to be what they ought to like in their own selt interest.***" This sounds like the talk of a man who wants to take over your thinking!! Watch for him!! He can succeed only if you let him!

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Wayne I. Pribble

WAYNE I. PRIBBLE, President

Cleveland-Akron

'Past Presidents Night' Becomes Tradition; Certificates Presented

R. M. Hershey

The February meeting of the Cleveland-Akron Section of SPE featured "Past Presidents Night" and an address on "Modern Instrumentation for the Plastics Industry" by Mr. Conrad Claeson, Director of Education, Wheelco Instrument Div. of Barber Coleman Co.

"Past Presidents Night" will be celebrated annually by the Section at the February meeting. At this meeting certificates of appreciation for contributions toward the betterment of the Society of Plastics Engineers will be awarded to the outgoing president. It is hoped that past presidents will regard the meeting as an annual reunion.

The initial "Past Presidents Night" featured the awarding of certificates to nine past presidents by H. D. Oliver, Jr., President of the Section. Ren Morse one of the founders of the Section and 1943 President was unable to be present but sent a very interesting letter on the history of the Section and the National Society. Howard Nichol, 1945 President also was absent. The following seven Past Presidents were present at the meeting: Dick Huber, 1949; Ward VanOrman, 1950; Wayne Anderson, 1951; Frank Martin, 1952; Dave Sloane, 1953; Ernest Moslo, 1954; and Sherman Crawford, 1955.

A surprise presentation of a Hamilton wrist watch engraved "Frank Martin—Chairman 1956 SPE Conference" was made to Frank Martin, by Herb Oliver in recognition of his contributions towards the success of the Conference.

In his talk, Mr. Claeson described the various types of control instruments used for the temperature control of extruders and injection molding machines. Slides showing wiring diagrams for the various types of instruments were shown.

It was stated that the proportionating type pyrometer is replacing the on-off type instrument for plastics temperature control problems. In the proportionating type of control the amount of heat input is determined by the position of the indicating pointer in the proportionating band. Below the proportionating band full heat input is applied. The width of the proportionating band is usually expressed as a percentage of the total scale reading. The desirable width is chosen as a compromise between on-off performance if the width is too small and excessive offset if the width is too wide.

Two methods of overcoming the offset or droop characteristic of proportionating controllers were described. Offset is regarded as the lag of the indicator pointer below the control point and may be compensated for by setting the control point higher than the desired temperature or by relocating the proportionating band with respect to heat input at the control point. The normal location of the proportionating band calls for fifty percent of heat input at the control point in order to maintain constant operating temperatures.

At the beginning of the year, three new Directors of the Section were elected by the members. They are Douglas G. Eaton, Reed Prentice Corporation; Donald H. Lewis, Packard Electric Div., G.M.C.; and William E. Manring, B. F. Goodrich Chemical Co. Ernest P. Moslo, Moslo Machinery Co., was re-elected National Director. In addition to the above our complete Board of Directors now includes H. D. Oliver, Jr., Eastman Chemical Products; G. H. Shirley, Colonial Plastics Mfg. Co.; W. F. Anderson, Anderson and Co.; K. M. Keller, Keller Products, Inc.; A. E. Campi, International Molded Plastics, Inc.; and R. M. Hershey, Hoover Co.

The following officers were elected for 1956: H. D. Oliver, Jr., President; A. E. Campi, Vice-President; D. G. Eaton, Secretary; and K. M. Keller, Treasurer.

Our President announced the following as Committee Chairmen: Professional Activities, Ernest P. Moslo, Moslo Machinery Co.; Membership, Carl W. Virgin, Spencer Chemical Co.; Credentials, Jack R. Pectal, Eastman Chemical Products, Inc.; Program, J. R. Forsyth, Crucible Steel Company of America; House, Edward J. Haskins, Zenith Plastics Company; House, Bernard J. Wuff, Injection Molders Supply; Educational, Granville H. Shirley, Colonial Plastics Mfg. Co.; and Journal Reporter, Robert M. Hershey, Hoover Company.

Spray Painting

A new brochure on an automatic rotary gun spray painting machine and an automatic rotary wiping machine is now available to anyone addressing their request to Conforming Matrix Corporation, 379 Factories Building, Toledo 2, Ohio. It includes illustrations and complete description of the model RM 26 rotary gun machine and the model DW 24 RT rotary wiper.

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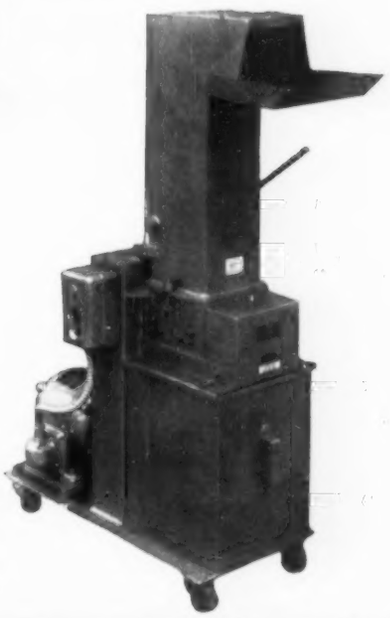

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Chicago

Polyurethane Plastics Properties And Uses Are Reviewed

Lloyd E. Parks

Mr. Richard B. Burck of the Mobay Chemical Company, Research Department, presented a detailed study of polyurethanes. The chemistry of the compounds and the most up to date information on processing and use were given.

Synopsis of Lecture on Polyurethane

Introduction

Isocyanate chemistry goes back over 100 years when the preparation of simple isocyanates and some of their reactions were reported, but the commercial importance of these versatile materials did not begin to appear until the period of 1934 to 1937.

We in the United States did not put forth a real effort in this field until after World War II when news contained in PB reports indicated extensive German developments in urethane coatings, foams, adhesives and fibers, but it has only been in the recent past that the promise of large scale production has promoted large commercial utilization. Farbenfabriken Bayer of Leverkusen, Germany, has been very active in this field for over 30 years; as the result of Farbenfabriken Bayer's work, Germany has had urethane coatings and urethane foam on the market over five years. Mobay Chemical Company was formed a little less than two years ago by Monsanto Chemical Co. and Bayer to make available to American industry the know-how and techniques developed in the use of isocyanates both in Europe and the United States.

The different isocyanates now commercially available include:

1) Toluene diisocyanate — a water thin, straw colored liquid. It is most generally used in making urethane foams and is also used in adhesives and coatings formulations.

2) Diphenyl methane diisocyanate, available in solid form and also in solution and used in adhesion applications; usually in a rubber to fabric bond.

3) Triphenyl methane triisocyanate, normally used as a 20% solids material as an adhesive for bonding rubber to metal.

The isocyanates with the greatest interest for coatings work are Mondur C, Mondur CA and Mondur S. These are partially reacted isocyanates or adducts, and are mixed with select polyesters to formulate one or two part coating formulations.

By the proper selection of isocyanates and polyesters and by controlling pertinent factors, reactions can be used to lengthen the polyester chain and cross-link the molecules to give you a foam or a rubber-like product, or a tough elastic film with exceptional chemical, solvent head and abrasion resistance.

Foams

Urethane foam is probably one of the most spectacular of the various products made possible by isocyanate chemistry. The ability to control the hardness and the flexibility of this product makes it unique and makes possible its use by many different industries. Foam can be made in large blocks which can then be cut or sliced into any size or shape, or foam can be molded in place to any given size or shape and thus become an integral part of a given structure. It can be made rigid or flexible; its density can be varied from 1 pound per cubic foot to 30 pounds per cubic foot and its cell size can be controlled and varied to suit the requirements of most any end-use.

The flame resistant characteristics make this foam ideal for use in public auditoriums, hotels, buses, trains, and other places where fire can be a hazard; that same property plus its light weight makes it ideal for the aircraft industry.

Whereas the flexible foams are predominantly open cell in structure, the rigid foams are closed cell and are available in density varying from 2 to 30 pounds per cubic foot. This type product has already been used by the aircraft industry as a reinforcing filler for cavities in wing tabs, elevators, ailerons, radomes, and for insulating cabins. It is being evaluated by the railroad industry for reinforcing and insulating lightweight cars and it has already passed the research stage for use in the construction of non-sinkable boats and pontoons.

The dielectric, chemical resistance, thermal resistance and insulation properties are good which opens still new and bigger fields for the use of rigid foams.

Coatings

Even though urethane coatings are new to the United States, we are extremely fortunate in having three or four years of field application experience in Germany to give us the necessary background data required to discuss urethane coatings as proven products. Mobay has had development, sales and research personnel inspect the many applications and discuss both the favorable and unsatisfactory properties of these coatings with people who have applied them and observed their performance.

The one quality which we had not previously appreciated but which use in a steel mill has brought out very forceably is the excellent **heat resistance** possessed by urethane coatings.

In several other instances chemical plants have been coated and here the isocyanates are subjected to severe **heat and chemical vapor exposure.** In a rubber accelerator plant, a urethane coating is exposed to the hot fumes of hydrogen sulfide, amines and strong hydrochloric acid without noticeable deterioration.

Unpigmented clear coatings show no indication of chalking, but 45° roof tests indicate a loss of gloss in color coats.

In spite of this our people have seen equipment in the field that has been in service for 2 to 5 years and they have observed only slight loss of gloss in pigmented coatings.

A second problem is that most of the isocyanate coatings prepared to date show **slight yellowing** on exposure to sunlight. As yet, we have found no stabilizers which will correct this. In the colors used for industrial equipment, this yellowing is not noticeable.

Moisture resistance and abrasion resistance have both been proven excellent and add to the advantageous properties of these coatings.

One of the best examples of **corrosion resistance** has been the use of these coatings in the holds of ocean-going tankers which carry sour crude from the Persian Gulf into Europe and salt water balast on the return voyage.

We can also report having seen them in slaughter houses, dairies and breweries where the ease of cleaning and sanitation are important. In Europe the coatings are used to line tanks for the storage of potable water; also tanks for storage of edible liquids such as wine, fruit juices and fruit syrups.

In discussing coatings, one of the first commercial applications in this country is the use of urethane coatings on magnet wire. The physical properties of the coating plus the excellent dielectric properties and moisture resistance make the urethanes ideal for use on wire. The one principal advantage which makes its use most outstanding is the property of solderability; with the urethanes no enamel stripping is necessary prior to soldering and it results in savings of both time and money when magnet wire of this type is used in the television, radio and the ever-growing electronics industry.

Vulcollan

One use of the isocyanates which has had a great deal of publicity is urethane rubber; the Germans call it Vulcollan.

Vulcollan is used to make such pro-

ducts as gears, bearings, shoe heels, handles for a jack hammer, timing gear for a motor cycle, and the like in Germany. There are others such as hydraulic accumulators, bellows, various types of contact drive wheels and many more. It is the combination of excellent abrasion, tear and wear resistance plus flexibility and oil resistance, which makes Vulcollan so suitable for these uses.

Multrathane

One of the urethanes which you as plastic engineers will have the greatest interest in, are what we have trade-named Multrathane or what Farbenfabriken Bayer in Germany markets as Durethane. These are linear materials of high molecular weight built up from dialcohols and diisocyanates possessing the following characteristics: high mechanical strength, a high degree of resistance to solvents and oils, low water absorption, good dimensional stability, good electrical properties.

The Multrathanes are generally processed by injection molding and extruding and they may also be molded by compression.

The special properties of the Mutrathane materials would make them suitable for such potential uses as:

1) In molding of bearings, fittings, bushings, handles, caps, gears and various structural components for a variety of home appliances.

2) Wire coverings for cables, wire rope, etc.

3) Blown foils for packaging, tapes for cable wrappings, linings, etc.

4) Bottles and hollow ware.

All of these various type products have actually been made and used in Europe. We ourselves have done very little to develop markets for the Multrathanes in this country as we are not sure just how they will compare in properties with other materials now commercially available.

Adhesives

Isocyanate adhesives have a longer history of use in this country than any other end use of isocyanate products; the need for a good adhesive to bond nylon tire cord to natural and synthetic rubber prompted their development.

We have now available as the result of German research, new urethane adhesives which will increase their usefulness. We call them "Multranils"; one adhesive is especially suited for flock printing and makes possible a product which is resistant to drycleaning, washing, hand rubbing and is yet soft and very flexible. Not only can fabrics be flocked but here is an example of a urethane foam bath mat flocked with a blue fabric. The second Multranil adhesive appears to be most suitable for bonding leather and rubber to themselves to each other and most non metallic products to themselves and each other.

Pioneer Valley

Ehlers Explains Lowell Program

John T. Moore

On January 26th, this section met at the Wachusett Country Club, West Boylston, Massachusetts for its initial meeting under its newly approved name, The Pioneer Valley Section. Ninety-one members and guests enjoyed the specialty of the house, about fifteen cubic inches of fine roast beef —with seconds for those who could hold it.

Mr. F. R. Schreiter, President, introduced his fellow officers, directors, and committee-men, comprising the first regularly elected leaders of this new section. Mr. Albert McIntyre, Section National Director, reported on the Directors Meeting held in Cleveland earlier in January. He also presented to Mr. Schreiter the Section Charter, which we shall duly frame.

Mr. Richard Bishop, Section Vice-President, introduced the speaker for the evening, Dr. Russell Ehlers, head of the Department of Plastics Chemistry, Lowell Technological Institute, Lowell, Massachusetts. The subject of Dr. Ehlers' talk was "The Problems Of Establishing A Plastics Engineering Course."

The National Education Committee of the Society of Plastics Engineers, Inc. has long advocated establishment of plastics engineering courses by the country's technical schools. Dr. Ehlers told us that to his knowledge this course offered by Lowell Technological Institute is the first established integrated curriculum in Plastics Engineering culminating in a B.S. degree. Acceptance of the course was immediate as evidenced by its high place among first and second preference engineering courses elected by incoming students.

The planning of the curriculum of the course has been very thorough. Taking all factors into consideration, it was decided to emphasize the study of engineering principals as applied to fabricating plastics materials rather than concentrating on the chemistry and theory of high polymers used in the manufacture of the materials themselves. The basic science and engineering courses form the foundation of the plastics curriculum. Applications and illustrations directed toward the field of plastics have been added to these subjects with due care not to jeopardize the important role played by other basic structural materials.

In the first two years, the student has little choice in the selection of courses. However, in the Junior year,

(Please turn the page)

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Pioneer Valley

(Continued from preceding page)

he is offered a choice of elective courses based on the humanities and social sciences; thereby broadening his outlook and developing his ability to present clearly and effectively the results of his scientific investigations. The student may choose a correlated sequence of electives from one of four groups of optional courses in the area of finance, management, sales, or the humanities. About 20 per cent and 35 per cent of the credit hours in the junior and senior years, respectively, are for electives.

The program of training is designed to prepare the graduate plastics engineer for a professional as well as a business career. His background will qualify him for plastics development, production, or sales. Further study would be required for a position in the field of fundamental research.

Dr. Ehlers listed the equipment on hand and being procured for the course. It includes blenders, compounding mills, preformers, compression and injection presses, extruder, vacuum metallizing equipment, calender, and miscellaneous testing equipment. He mentioned the problems in procuring a teaching staff and accumulating reference library material. Local plastic fabricators have already been in contact with Lowell Technological relative to summer employment of students. Dr. Ehlers stressed the importance of this to the students and encouraged more action of this type by industry.

After a period of questions and answers, the proposal was made by Mr. John LaBelle that our Section provide Lowell Technological Institute with twenty copies each of the book of reprints of the technical papers presented at the 1955 and 1956 National S.P.E. Conferences. This was unanimously adopted and a fund of $90.00 was raised for the purpose. It is hoped that National Headquarters will cooperate in making these available.

Balfor Industries

Balfor Industries, Inc. announces that it is now in full production in all phases of Teflon processing.

Balfor Industries, Inc. a newly organized company with offices and plant at 1815 Webster Avenue, Bronx 57, New York, is specializing in the manufacture of Teflon products. Executives of the new company are: Mr. Donald E. Ballot, President; Mr. William J. Fordon, Secretary-Treasurer; and Mr. Robert B. Sweet, Sales.

Toledo

Speaker Tells of Higher Efficiency With Machines

C. A. Richie

Thirty-seven members of the Toledo Section of the Society of Plastics Engineers met on Wednesday evening February 15th at Harrison's Ranch House Restaurant for a dinner meeting. Our section welcomed the opportunity of hearing Mr. Quenton M. White of F. J. Stokes speak on "Automatic Molding."

Mr. White was very convincing by showing actual production figures with 10-20% higher efficiency on a 24 hour basis when using their automatic equipment even at slower cycles than with a semi-automatic press with operators. The fact that the stripping comb worked independently by use of hydraulic ejectors impressed several of our local injection molders. The tremendous potential accompanied by improved operating efficiency with ultimate savings to all concerned assures the future of automatic molding.

Calculation of Roll Forces . . .

(Continued from page 40)

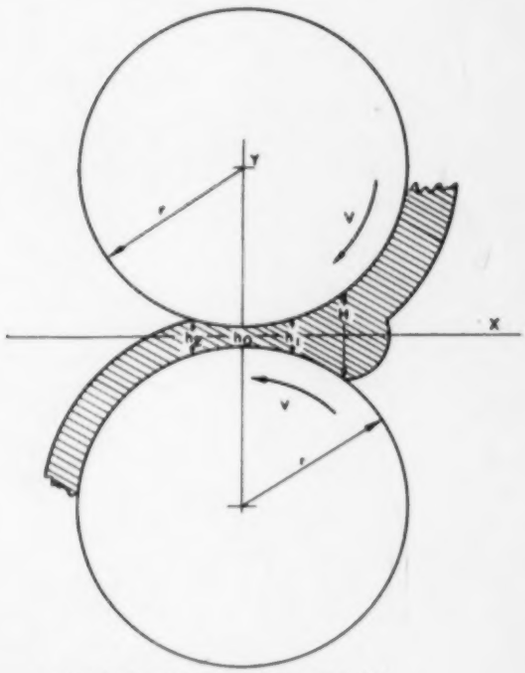

ILLUSTRATION OF ROLLING PROCESS AND COORDINATE SYSTEM
FIGURE 5

$$\tau(\text{sub s}) = 2x_1/V \qquad (18)$$

where x_1 represents the distance from h_∞ to h_1. On the basis of (6) and (9), x_1 may be put in terms of r and h_∞, giving

$$\tau(\text{sub s}) = 2(r\,h_\infty/3)^{1/2}/V = (2/3^{1/2}\,V)\,(r\,h_\infty)^{1/2} \qquad (19)$$

Combining (17) with (19), one has

$$\tau(\text{sub s}) = (4/3^{1/2}S)\,(r/h_\infty)^{1/2} = (2.31/S)\,(r/h_\infty)^{1/2} \qquad (20)$$

which gives the value of relative shear time to correspond to that given by Equation (4). Separating the geometric factor from the shear rate in (20) one has the dimensionless number

$$2.31\,(r/h_\infty)^{1/2} \qquad (21)$$

which, similar to the number 4L/R used in extrusion measurements, is the basis for evaluating the shear-time adjustment factor from Figure 2.

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Plastics Around the World

(Continued from page 50)

REINFORCEMENT OF PRE-STRESSED CONCRETE WITH FIBRE GLASS TENSION MEMBERS —W. Mack

Reprint of address held at 11th Annual Technical Conference of SPE.

COMPRESSION OR TRANSFER MOLDING—H. Draeger and W. Woebcken

Advantages and disadvantages of both processing techniques are juxtaposed resulting in the conclusion that small to medium size parts of complicated shapes or thick walls and required in large quantities are best transfer molded while compression molding remains preferable for large size, thin walled, flat or box-type parts.

DESIGN OF INJECTION MOLDS—Hans Gastrow

Description of design features of injection molds with exterior undercuts in moldings and automatic tang break-off device.

★

GREAT BRITAIN

PLASTICS

December, 1955

Abstracter: Alfred T. Rexter

AUTOMATIC DIP-MOLDING

The construction and operation of a large automatic p.v.c. dip-molding plant is described with several illustrations.

PLASTICS AID RESIDUAL PRODUCTS CONVERSION — Thomas A. Dickinson

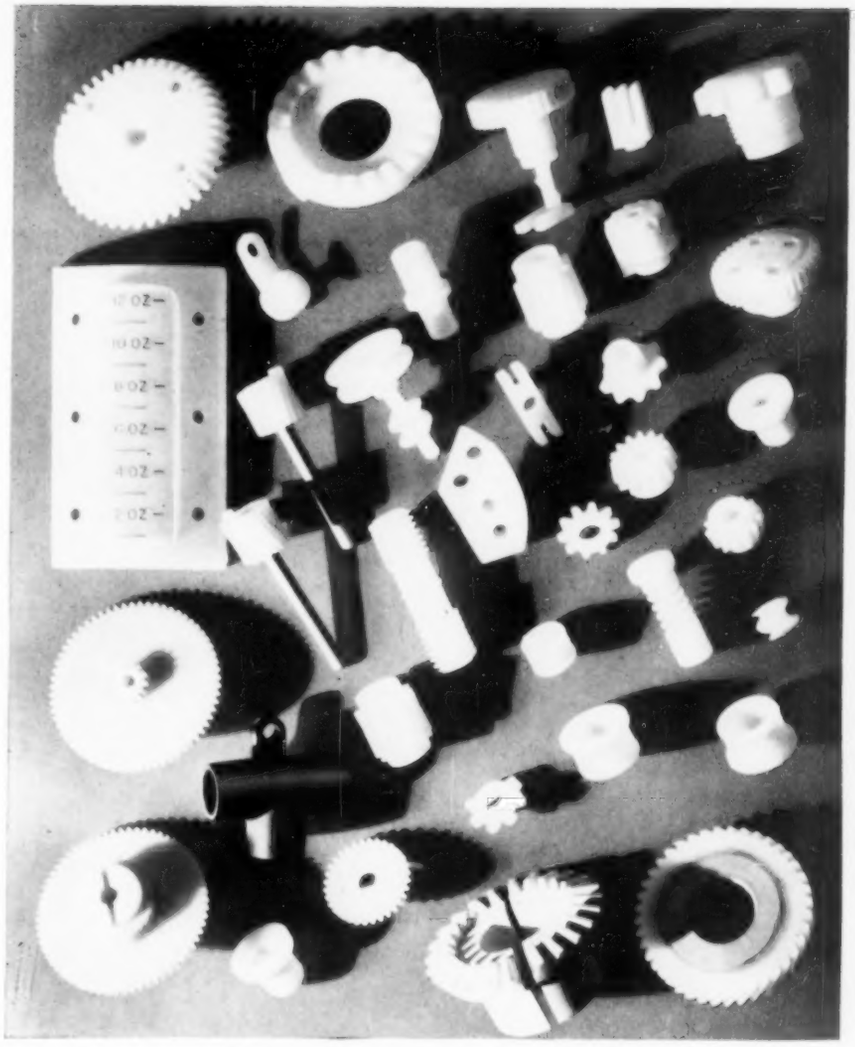
Waste products, such as leather dust and wood flour, are being put to good use with the aid of certain plastics. Three types of organic resins are generally used: phenolic and urea thermosets; synthetic elastomeric thermoplasts; and natural elastomers. A wood reclamation method, an electrostatic coating process, and a solvent dispersion method are described.

DRYING AND HEATING BY HIGH-VELOCITY AIR

Machinery has been developed which is now being used extensively for the fusing of p.v.c. and fabric. A description of the work done by the Spooner Dryer and Engineering Co., Ltd.

THE PROPERTIES AND TESTING OF PLASTICS MATERIALS (CONT.)—A. E. Lever

This article is in two sections, one covers the testing methods and results for viscosity, plasticity, and flow; the other covers resilience, stiffness, and damping.



Have You considered NYLON for Mechanical Parts?

The above illustration shows only a few of the many parts being injection molded of Nylon.

The advantages of producing these parts in Nylon are—

- Lower Cost
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- Needs No Lubrication
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book reviews

HANDBOOK OF TOXICOLOGY, Volume I. Acute toxicities of solids, liquids and gases to laboratory animals. Edited by William S. Spector. W. B. Saunders Company, Philadelphia and London, 1956, 406 pages, paper. $7.50.

This work was prepared under the Direction of the Committee of the Handbook of Biological data: Division of Biology and Agriculture, National Academy of Sciences and National Research Council by 30 contributors. The first table, containing 315 pages, gives the lethal doses of 2,120 solid and liquid compounds. In some cases, figures are given for only one species of animals, in some others, for several species including frogs, toads, mice, rats, guinea pigs, rabbits, pigeons, chickens, dogs, cats and sheep.

The table gives the nature of the animal, the kind of dose administered, the concentration in mg/liter and ppm, the exposure time, time of death and author references. Table II gives the lethal concentration of gases, vapors and fumes in respired air. It contains 243 compounds, including fumes of chemicals widely used by the plastics industry.

Plastics engineers and chemists will find here valuable toxicological data on plastics, plasticizers, solvents and other chemicals of interest to them.

Louis C. Barail

Electric Insulation and Dielectric 1955, an Electrical Manufacturing Design Manual

A reprint of the outstanding papers presented in Electrical Manufacturing during the year 1955 with editorial comments by the publishers is presented in a single volume.

The work book reviews progressive work with the more recently developed materials by classes with emphasis on design and use. Actual case applications are reviewed and test data is generously presented. Theoretical considerations are dealt with sparingly. Research problems are wisely left to the scientists. This is a work to be valued by the application engineer.

J. C. Stansel

Handbook of Textile Fibers

Edited by Milton Harris; Published 1954 by Harris Research Laboratories (Washington, D. C.); 356 Pages, Price $12.50.

The "Handbook of Textile Fibers" was prepared, the Editor states, " . . . not only for research workers, but also for all those who have interests in the textile or related industries." It may be noted that the "Handbook" is uniquely a contribution of Harris Research Laboratories, since not only the Editor but six of his eight editorial assistants represent that organization.

The "Handbook of Textile Fibers" deals with both natural and man-made fibers, whether organic, inorganic (like glass and asbestos) or intermediate in nature (like "Teflon"). It presents a staggering mass of data compiled in an orderly and easy-to-assimilate form, usually as either tables or graphs. No less than 450 tables and 100 graphs, diagrams and figures are included in the 356 pages.

The book contains twelve chapters: Textile Terms and Definitions (31 pages), Fiber Types and Sources (16 pages), Constitution and Structure of Textile Fibers (45 pages), Chart of Fiber Properties (7 pages), Physical Properties of Textile Fibers (73 pages), Chemical Properties of Textile Fibers (13 pages), Effect of Biological Agents (5 pages), Identification of Textile Fibers (13 pages), Yarn Numbering and Count Systems (12 pages), Chemical and Engineering Tables (12 pages), Economic and Production Data (27) pages), and List of Textile Periodicals (2 pages), plus an Index (17 pages covering approximately 2700 items). Noteworthy features among these chapters are the approximately 1800 definitions of textile terms and the clear and concise treatment of the constitution and structure of fibers, including the 130 microphotographs and X-ray diffraction diagrams of various fibers.

The entire publication gives evidence of careful consideration for the convenience of the reader, being well organized and indexed. The omission of a section on textile and fiber testing methods and apparatus would appear to provide the only basis for even mild criticism of this book.

Because the fields of textiles and plastics ordinarily are widely separated and distinct, it is not likely that many S.P.E. members will find themselves in a position to utilize this useful book to the fullest extent, but those whose interests extend into the textile field, whether as technical or non-technical workers, will find the "Handbook of Textile Fibers" a storehouse of information.

D. E. Cordier

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SPEaking . . .

(Continued from page 49)

the lands, where the greatest abrasion occurs. Normally, flight lands are either flame hardened or stellited. Such details as flight depth, helix angle, land width, screw clearance, and length should all be considered as they affect both quality and output.

It is usually desirable to core the screw either partially or fully in order to permit the circulation of water or other cooling medium through the center of the screw. Through the proper manipulation of the cooling medium, it is possible to vary the general characteristics of the screw.

THERMODYNAMIC

The two conventional methods of providing thermal transfer in extruders are circulating fluids and electric. Either system performs satisfactorily but in selecting the type, consideration should be given to the expected use.

The following presents items to be considered and a brief description of each.

1. The expected maximum temperature should be determined by familiarity with the processes involved.
2. In the oil heated extruder, the oil is electrically heated and pumped continuously through the channels of the cylinder. The important factor to consider on an oil or other liquid heat exchanger is the piping and pump system. Leaks which occur during operation tend to be of concern for cleanliness and maintenance problems. The upper temperature is limited but normally closer temperature control is obtainable.
3. Electric heat is more common and the recent variations in designs of electrical heated extrusion machines bear out the emphasis of good control on thermal transfer.

Points to be considered are:

a. Type and design of heater, whether band or strip heater, cast in aluminum.
b. Type of insulated shield.
c. Total kilowatt load.
d. Kilowatts per section.
e. Location of thermocouples and type (ion-constantan).
f. Accessibility of heaters for periodic inspection, repairs or replacement.
g. Number of heating zones.
h. Instrumentation.
i. Power requirement (voltage, phase, cycle, current).

In conclusion, making a thorough evaluation of extrusion equipment in addition to assisting one in obtaining the best equipment has a secondary effect of making one more familiar with many aspects of the process.

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Midwest — AAA — I Rating. Compounding and custom operation require experienced man for die design. Development and sampling. Give full resume of experience, education references and salary requirements in first letter. Replies held confidential. Box #1256 SPE Journal, 34 East Putnam Ave., Greenwich, Conn.

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Company in California, specializing in Polyester Molding Compounds, with many years of successful operations, has opening for man with degree and experience. Will have to work on new formulations, testing and quality control. Complete resume and salary requirements should accompany first letter. Replies will be held in confidence. Reply Box No. 1156, SPE Journal, 34 East Putnam Avenue, Greenwich, Connecticut.

Plastic Sales Engineer

We are seeking a well qualified man experienced in plastics extrusion for attractive Market Development position. Kindly give your education, experience, and expected salary in complete resume. All replies will receive careful attention and will be held confidential. Write: 108 Personnel Department, Chemical Division, Koppers Company, Pittsburgh 19, Pa.

Wanted—Plant Manager

With experience in Matched-Metal reinforced plastic molding and Premix molding. Well established Ohio company. Expanding molding operations. Real opportunity. Salary open. Write giving full details. Box 1356 SPE JOURNAL, 34 E. Putnam Ave., Greenwich, Conn.

Opportunity in Plastics Extrusion Production and Development

Long established company in Eastern Massachusetts, diversifying in plastics, needs young competent extrusion engineer to assume responsibility for production and product development. Experience in the extrusion of various plastics required and knowledge of raw materials essential. This is an excellent opportunity for future growth.

Please address letter with full details of training, experience, and salary expected to: Box 956, SPE JOURNAL, 34 East Putnam Avenue, Greenwich, Connecticut.

Mold Designer—

Expanding Mold making shop in Philadelphia, Pa. area making small and medium size injection, compression and Transfer molds. Has need of experienced man. Should have shop training and knowledge of molding. Excellent future for responsibility and supervision. Will consider man with limited experience for training. Give full details, salary, experience, training, etc. Box No. 856, SPE JOURNAL, 34 E. Putnam Ave., Greenwich, Conn.

Plastics Engineer

Young man between 25 and 35 years for research and development work, some traveling. Please give education, experience, salary desired. Reply Box 656, SPE JOURNAL, East Putnam Avenue, Greenwich, Connecticut.

Outstanding Opportunities in Plastics Manufacturing

Several positions in plastics and small metal parts manufacturing are open with a well-established manufacturer located in southern New England. The firm is now beginning a major expansion program providing outstanding job opportunities for qualified manufacturing engineers, quality control engineers and foremen.

1) QUALITY CONTROL SUPERVISOR for plastics operations. Must have previous experience in manufacturing and quality control or have engineering background.

2) GENERAL FOREMEN for plastics finishing department. Some previous experience in supervision required.

3) FOREMEN for compression, plunger and injection molding departments in plastics manufacturing.

4) Manufacturing Engineers for plastics and small metal parts manufacturing. Engineering degree or equivalent experience essential.

One of these positions could mean new opportunities for you. Send us a resume of your education and experience. All material will be held in confidence.

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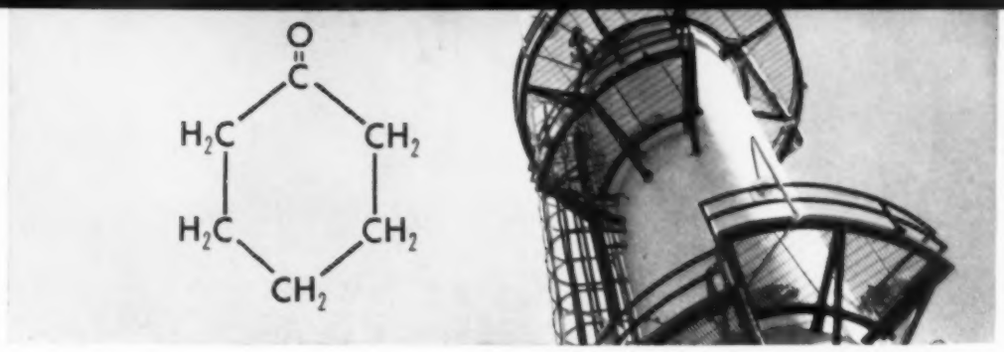

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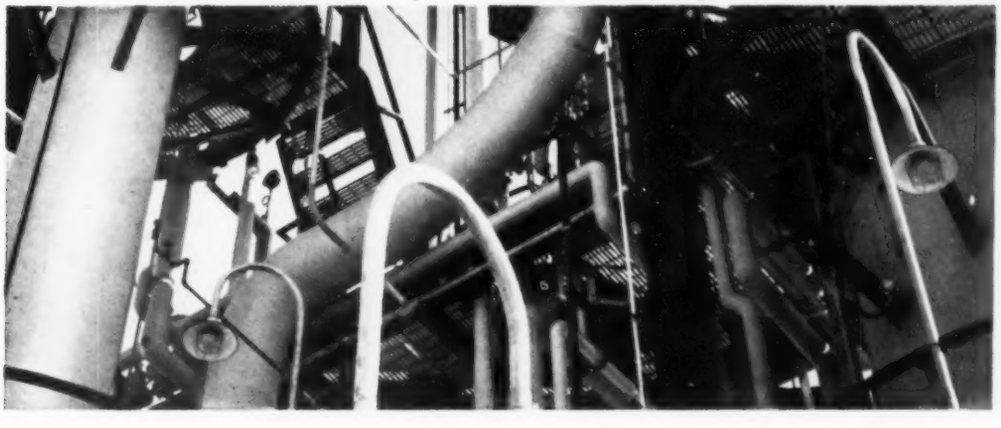

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facts about hi-fax

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Hi-fax is rigid and strong! Hi-fax has four to five times the rigidity of regular polyethylene. It has double the strength.

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Hi-fax is richly colorful with an attractive lustrous finish!

Hi-fax is easy to fabricate! Can be molded by compression, extrusion and injection techniques and machined by conventional methods.

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Cellulose Products Dept.

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